Collecting, Processing, and Germinating Seeds of Western Wildland Plants

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ABSTRACT

The culturing of native plant species is gaining in importance in the Western United States. The collection of seeds from native stands is often the only way of propagating these species. The general seed industry has developed many highly technical machines for harvesting and processing cereal, vegetable, and flower seeds. Examples are provided for adapting these machines for use with seeds of plants collected from wildlands. For the collector who wishes to process only a few seeds, numerous hand techniques are explained. Because abundant crops of seeds are not produced every year, it is desirable to store native plant seeds. Seeds must be stored carefully to insure viability. Many seeds of wildland species have dormancy requirements that must be overcome in order to culture these species. Few methods exist for overcoming the dormancy of most native plant species. Relatively simple tests can be applied to increase the germination of dormant seeds.

KEYWORDS: Native plants, seed cleaning, seed harvesting, seed storage, seed labeling, seeds of endangered plant species, germination enhancement.

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COLLECTING, PROCESSING, AND GERMINATING SEEDS OF WESTERN WILDLAND PLANTS

By James A. Young, Raymond A. Evans, Burgess L. Kay, Richard E. Owen, and Jerry Budy[1]

INTRODUCTION

The demand for wildland plants for revegetation of roadsides, mine dumps, and other harsh environments has created the need to develop efficient techniques for (1) collecting, (2) threshing and cleaning, (3) storing, (4) germinating, and (5) propagating seeds of these plant species.

Our purpose is to provide individuals interested in the propagation of wildland plants with a summary of the techniques we have developed from practical experience and from the application of knowledge from related fields.

SEED COLLECTION

Timing Collections

The timing of seed collection from wildland plant species is one of the most crucial and difficult steps in propagation. Collection of immature seeds results in low seed viability or dormancy. The dangers in delaying collection are that the fruits of many wildland plants dehisce (fall from the seed head[2]) very rapidly and seeds are lost if collection is delayed. Collecting seeds from the ground may be possible, but usually results in low-quality seeds and excessive cleaning costs.

Most crop plants bloom in sequence, beginning with the uppermost or central flower; therefore, these plants have a determinate inflorescence or flower arrangement. In contrast, many wildland plants have indeterminate inflorescences where the flower stalk continues to grow with prolonged flowering and many different stages of seed maturity on the same stalk. This makes uniform seed col-

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[2]See glossary of technical terms, p. 41.

lection difficult. If the seed collector is able to selectively harvest only the ripe portions of the inflorescence, the indeterminate inflorescence is no great problem.

There is no substitute for experience in judging when to collect seeds of wildland species. To start a collection program for a species with which you have no previous experience is difficult. Guides to maturity can be obtained for regional floras. Such manuals usually provide a range in maturity (for example, late June or July). More detailed information can be obtained from the few specialty manuals or articles that deal with the collection of seeds of native plant species (Emery *1964*).[3] The original "Woody Plant Seed Manual" (USDA *1948*) and its more recent edition (Schopmeyer *1974*) provide guidelines for the woody species. The old and difficult-to-obtain bulletin "Collecting and Handling Seeds of Wild Plants" (Mirov and Kraebel *1939*) is an excellent source of information for California collectors.

Considerable information is available concerning seed collection of the important browse species bitterbrush [*Purshia tridentata* (Pursh) D.C.]. The seeds of this shrub are collected by personnel of land management agencies and professional seed collectors. Nord (*1963*) pointed out that bitterbrush seed production may be forecast a year before the fruit develops. Because bitterbrush flowers on second-year twigs, good crops generally follow years of average or better moisture and when stem elongation averages at least 3 inches. For species that fruit on the current year's wood, this observation would not be valid.

Essentially, the novice seed collector must judge plant phenology or the sequence of plant development. Flowering is the first phenological stage of which the would-be seed collector must be cognizant. Flowering is obvious for many species with colorful petals, sepals, or bracts, but careful attention is required to note anthesis (shedding of pollen) with many grasses. After flowering, the sequence of phenology is as follows:

1. *Soft-dough stage*.--This stage is indicated by the excretion of dough from seeds when squeezed between the thumb and forefinger. Seeds collected at this stage generally have low viability if they will germinate at all.

2. *Hard-dough stage*.--The hard-dough stage can be judged by biting the grain, once the milk or dough stage is completed. Once the seed is fully mature, it is usually too hard to bite. Seed collection should start with the transition from soft to hard dough. The time interval between soft and hard dough is a good indication of how soon to repeat the collection. With these first collections, the chance of obtaining plump, fully matured seeds can be increased by not stripping the seed from the plant, but rather by cutting considerable plant material. In some species, this method will continue the maturity process. Care must be taken to insure that the mass of plant material dries uniformly and does not mold.

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[3]The author's name, followed by the year in italic, refers to Literature Cited, p. 39.

3. *Maturity*.--Obviously, the goal of wildland seed collectors is to harvest mature seeds. Unfortunately, maturity and seed dehiscence may occur at the same time. To make sure some seeds will be obtained, repeated collections are necessary. These collections extend from the latter part of the soft-dough stage until all seeds are lost. Each collection must be clearly labeled with the collection date, location, species, and stage of phenology based on physical appearance. Descriptive notes on associated plant or site factors that may aid in reidentification of the stage of maturity are valuable.

For large-scale collections of seeds of wildland species, seed-moisture curves will be valuable guides to proper timing of harvesting. Moisture is high in immature seeds, usually about 60 percent, but drops to about 10 percent as the plants mature (Harmond et al. *1961*). The seed-moisture curve for each species will show a characteristic shape because of differences in the slope or drying rate. The rate of seed moisture change varies with climatic conditions, but averages about 3 percent per day during the seed maturity period. With above-average hot weather, the slope of the curve temporarily increases; whereas, during cooler rainy weather, the curve flattens. For many crops, the seed-moisture curves are known and are used for guides to harvesting seeds. Methods of determining seed moisture are provided in the seed storage section of this manuscript.

Germination tests on each collection, made over a period of phenological development, provide the ultimate basis for the correct time to harvest. Remember that optimum germination may occur in the most mature seeds, whereas seed yield may occur at an earlier stage of maturity before seeds are lost by shattering. Because of year-to-year variation in growing conditions, no method provides an absolutely accurate prediction of the specific date for seed collection.

The period of optimum seed collection can be extended by starting seed collection at low elevations and following maturation upslope. The same procedure can be applied to species that produce tillers that mature later than the main inflorescence.

Nord (*1963*) found that 74 percent of the variability in date of seed ripening for bitterbrush was accounted for by variability in latitude and altitude. Through application of Hopkins' Bioclimatic Law (Hopkins *1918*), adding or subtracting one day for each 100 feet of elevation or 15 minutes latitude has led to a highly significant relationship between actual and theoretical seed ripening dates.

Often, the seed collector can take advantage of microenvironmental differences at a given location to aid in collecting mature seeds. If seeds are immature on north-facing slopes, plants of the desired species growing on south slopes will generally be at a more advanced stage of maturity. Plants growing in swales or along drainage bottoms may produce more seeds than the same species on arid south slopes.

Areas burned in wildfires are excellent for seed collection for several seasons after burning. This is a result of the natural plant succession following burning and the dynamic reproductive response of many species to reduction in competition and nutrient changes brought on by the fire.

Seed Caches

Rodents, birds, and insects, especially ants, are voracious collectors of some seeds. For some species, for example, juniper (berries) and pinyon pine (nuts), the seed collector must race the natural predators in order to obtain any seeds unless protective bagging or screening is used. Some seeds, especially conifers and bitterbrush, can be obtained from rodent caches. Seeds from warm desert annuals that have ant-attracting glands can be recovered from the refuse dumps of ant nests. For some species of ants, the viable seeds are stored in the nest, and only chaff is left on the soil surface. The droppings of many animals contain viable seeds or seeds that have improved germinability after passing through the digestive tract. The difficulty with any of these collection methods from caches or droppings is that the quantity of seeds obtained is small, and they are often contaminated with pathogens.

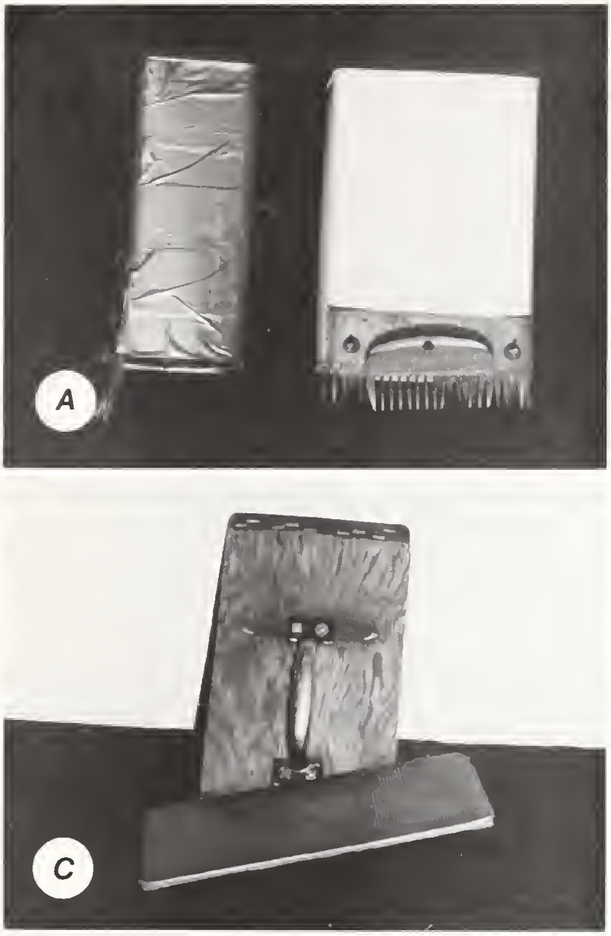
COLLECTION METHODS

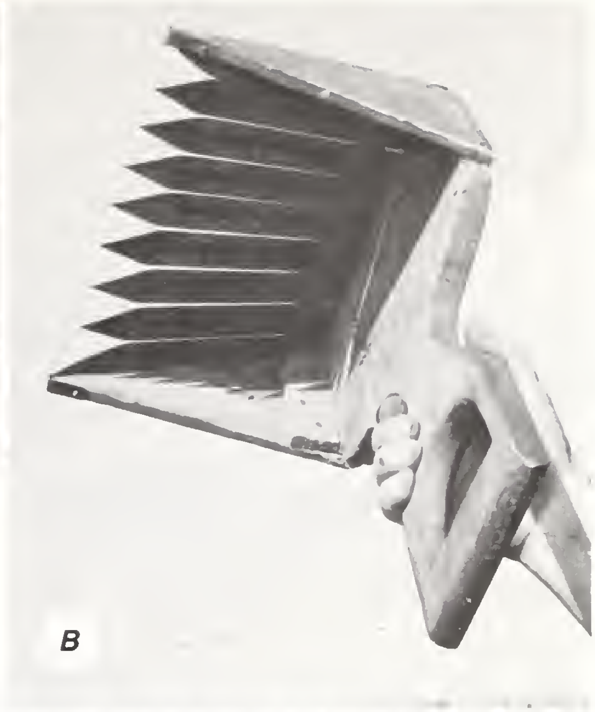
Collection methods are largely hand methods because the desired wildland species do not grow in pure stands, and the topography often limits use of mechanical equipment.

Grass Species

The seeds (caryopses) of grasses can often be collected by stripping. The stripper may be the collector's fingers or mechanical fingers on a truck-mounted or towed implement. The process consists of allowing the grass culms (stems) to collect between the fingers and the seeds to be scraped from the terminal inflorescence as the stripper moves forward. A simple seed stripper made from sheet metal and a gallon can may be a valuable tool for hand stripping (fig. 1). The culms of the grass plant fit between the teeth of the stripper, and the inflorescences are pulled loose to drop into the container. In dense stands of annual grasses, a garden rake can be used to strip the seeds of some species. For large-scale mechanical harvesting, the seed stripper is a very inefficient way of collecting the seeds. A number of native grass species cannot be harvested satisfactorily by any of the conventional mechanical means, such as field combines, making it necessary to strip. A flow diagram for Thurber's needlegrass (*Stipa thurberiana* Piper) seed collection is shown in figure 2. If wildland grass species occur in large enough stands or on topography that permits use of mechanical equipment, it is far more efficient to use a header or a forage harvester to collect the material for threshing than to attempt to strip the seeds. Headers are machines that clip the plants just under the seed head. Seeds are cured in piles and later threshed.

Forage harvesters can be used to chop mature grass stands. The chopped material is either cured for later threshing or the herbage and seeds are broadcast together at time of planting. This can be a highly satisfactory technique in local areas where long distance transportation is not involved. The herbage provides a mulch to help establish the desired seedlings.





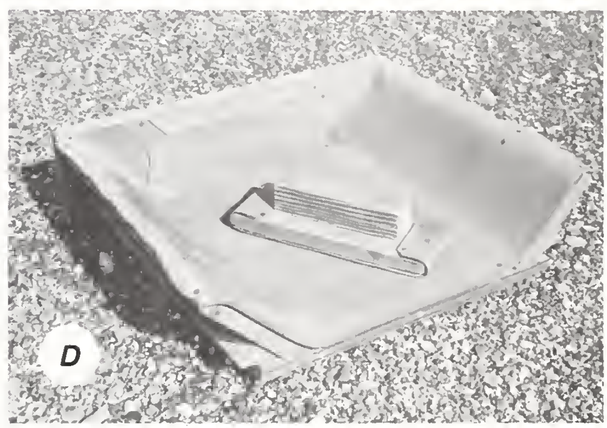


Figure 1.--Seed collecting and threshing equipment: *A*, Simple seed stripper made from gallon can and sheet metal; *B*, seed stripper made from wood and sheet metal; *C*, rubber-mat-covered paddles for threshing; and *D*, rubber-mat-lined threshing box and paddle.

Grass fields can be repeatedly harvested the same growing season by simple modification of a standard combine (Hary et al. *1969*). The cutter bar is covered with a section of split tubing or pipe so the grass stems are not cut, but slide under the combine. Before the grass stems slide under the covered cutter bar, extra large bats on the combine reel swat the seed heads, knocking mature seeds into the combine. Immature seeds remain in the seed heads and pass under the combine. The speed of the rotation of the reels should be increased four or five times over normal operating speeds for this system to work.

Many highly specialized harvesters, such as pneumatic-type strippers, bluegrass cylinder strippers, and suction seed reclaimers, are used commercially in the crop seed industry. If large-scale collection of a suitably abundant wildland species is being contemplated, it may be worth investigating this sophisticated equipment. A good source of information is Harmond et al. (*1961*).

McKenzie (*1977*) compiled the available literature on high-production grass seed collectors. This publication provides domestic and foreign sources of small combines and grass strippers. It also lists research organizations active in research and development of grass seed collection equipment and has a reference section for pertinent literature.

Broadleaf Herbaceous Species

The seeds of many herbaceous species can be collected by holding a tray or box under the inflorescence while shaking or flailing the mature seeds into the receptacle. For very small herbaceous annuals, the simplest method may be pulling the entire plant and bagging the material in paper sacks. Some herbaceous

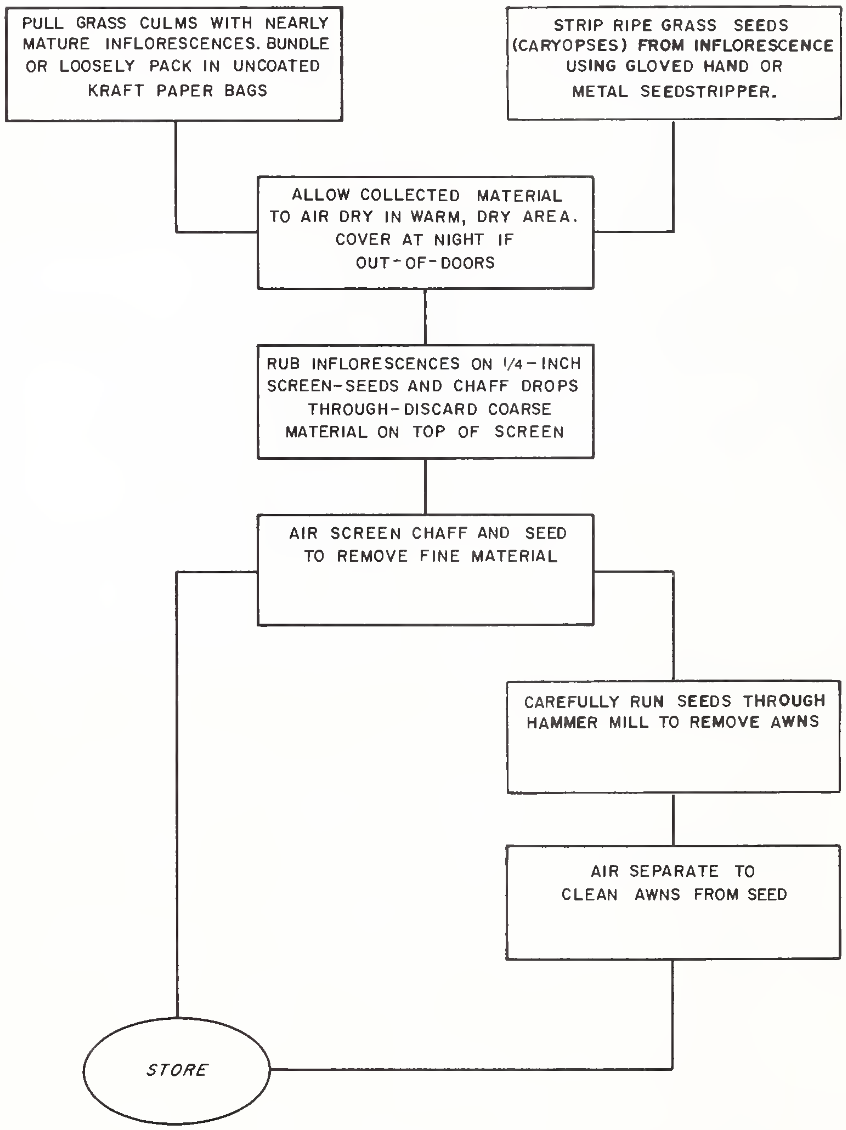


Figure 2.--Steps in collecting, threshing, and cleaning seeds of Thurber's needlegrass (*Stipa thurberiana*).

species have capsules or fruits that dehisce explosively. For these species, the entire inflorescence must be cut before maturity and allowed to dry on tarps or in mesh bags.

Collecting the entire plant is the only way to harvest seeds from spiny annuals such as Russian thistle (*Salsola iberica* Sen and Pau), where seeds are produced axillarly over all of the plant (fig. 3). When the entire plant is harvested, care must be taken to insure that the material dries without molding.

For herbaceous species that have spike-type inflorescences, pods can be stripped from the spike as with grasses. Lupines are a good example of a broadleaf plant where stripping is possible. The pappused seeds (achenes) of many of the species of the Compositae (sunflower) family can be lightly brushed or swept into bags if the collector times dehiscence perfectly. Some of the Compositae have large heads for inflorescence that are subtended by armed bracts or spines. These heads can be clipped and bagged for later threshing.

Shrub Species

The seeds of many shrubby species can be collected by holding a tray or box under the outstretched branches while flailing the bushes with a stick or paddle or by sweeping the arms across the upper branches to loosen the seeds, which then shower into the receptacle. For collecting bitterbrush seeds by hand, the Inyo tray was developed (Schneegas and Graham *1967*). It consists of an aluminum tray 20 inches long, 30 inches wide, and rounded at the bottom to a depth of 8 inches. A handle is inserted along the long axis. For limited collections, a cardboard box serves the same purpose as will baskets and canvas bags. A lightweight, 20-gallon barrel provides a ridged lip over which to bend shrub branches for removing fruits. This procedure is effective with spiny shrubs, such as desert peach, where the fruit must be physically stripped from the branches (fig. 4).

Shrubby species with explosive capsules, such as *Ceanothus*, must have the capsules stripped before maturity and ripened in mesh bags or on tarps to avoid seed loss. Canvas or plastic sheeting spread on the ground to collect seeds loosened from branches is of limited value because of the time and difficulty required to spread the sheeting under low branches and over rocks.

Trees

The coniferous trees are the most important wildland species whose seed is extensively collected and sold in commerce. The specialized techniques for collecting and threshing conifer cones are explained in depth in the recent edition of the "Seeds of Woody Plants in the United States" (Schopmeyer *1974*).

Species of *Populus* are important revegetation tree species in the Western United States. They are often propagated vegetatively rather than by seed. Seed collections require special techniques where branches with nearly mature fruits are cut and brought into a warm room or greenhouse and placed in water to allow the capsules to open.

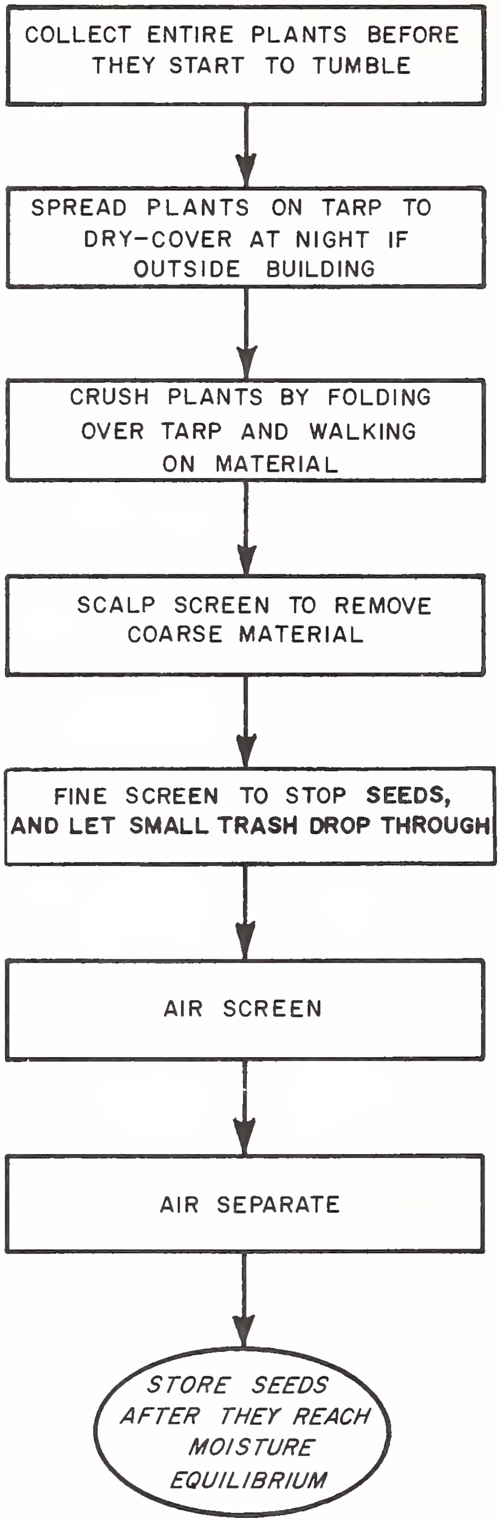


Figure 3.--Steps in collecting, threshing, and cleaning seeds of Russian thistle (*Salsola iberica*).

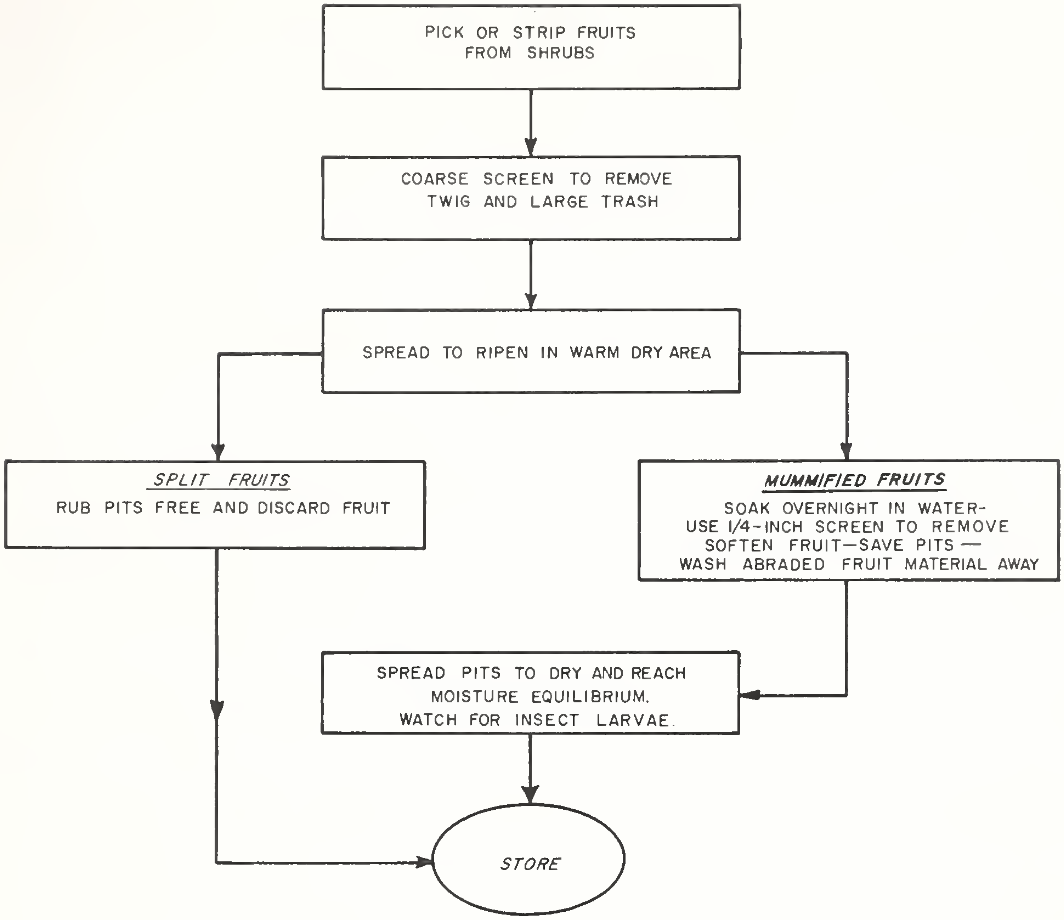


Figure 4.--Steps in collecting and cleaning pits of desert peach (*Prunus andersonii*).

Mechanical Harvesting of Tree Seeds

Mechanical tree shakers have been used to shake cones or fruits to the ground for later collection. Correct timing is necessary to limit damage to the trees.

Mechanical Harvesting of Shrub Seeds

Seeds of some semiherbaceous shrubs, such as fourwing saltbrush [*Atriplex canescens* (Pursh) Nutt.], can be stripped by tractor-drawn seed strippers. Combines (combination of headers and thresher) have been used to harvest winterfat [*Ceratoides lanata* (Pursh) Mog.] seeds (Plummer et al. *1968*). Field trials of vacuum harvesting, either vehicle mounted or a backpack model, have shown promise for harvesting seeds of several western shrubs.

POSTHARVEST HANDLING OF SEEDS

There is often a delay between collecting and threshing. This delay is necessary to allow fruits to mature and inflorescences to dry. The pressure of maximum collection during a short time period before dehiscence also delays threshing.

This delay period is important for seed yield and quality. We have stressed the use of mesh or paper bags for collection of seeds. Plastic bags or wax coated paper should never be used. The moisture content of the freshly collected seeds is quite high, and plastic or other nonporous bags will trap this moisture and cause spoilage of the seeds.

A ventilated greenhouse room (without evaporative coolers) is an excellent postharvest drying area for seed samples to be threshed. If the collected material is dried outdoors, provisions must be made to cover the seeds at night and in the event of winds, rain, or dew.

One method of reducing the amount of plant material to store and dry before threshing is to coarse screen the collected seed or fruit in the field. This simple process consists of screening the collected material through a screen with large enough openings to allow the seeds or fruits to pass through. Coarse trash and waste are left on top of the screen to be discarded. A second screening is made with a screen too small to allow the desired seed to pass through. The seeds are kept on top and fine waste passes through for discarding. Screens can be constructed from hardware cloth or fine wire mesh mounted on wooden frames.

THRESHING

Modern agronomic threshing machines are called combines because they are a combination of a feeding section (consisting of reel, divider, cutterbar, and . feeding mechanism) and threshing section. In harvesting seeds of wildland species, we rarely have the opportunity to use a combine. The processes inherent in the threshing section of a combine are worth reviewing because these same processes are necessary in hand or mechanical threshing.

Mechanical threshers consist of a threshing cylinder and fixed concave bars. The turning cylinder bars rub the herbage (straw) and seeds against the fixed concave bars. This action breaks the seeds or fruit bases from the inflorescences and often removes the glumes, bracts, pods, or fruits covering the seeds. The adjustment of the clearance between cylinder and concave bars is of the utmost importance in mechanical threshing. A general rule is to have a clearance of one and one-half times the thickness of long seeds or one and one-half times the diameter of round seeds (Harmond et al. *1961*.).

Some versatile small plot threshers are adapted to threshing small lots of seeds of wildland species (Harmond and Klein *1964*). Special rubber-coated concave bars are available for these small threshers to reduce damage to fragile seeds.

Hand Threshing

Hand threshing duplicates the action of concave bars in the mechanical threshing cylinders. The object is to rub the seeds to break loose the inflorescences or fruit covering.

A simple threshing method is to rub the collected material against a coarse screen. A more efficient method is to cover two wooden paddles with rough rubber matting (fig. 1). Rubbing the collected material between the paddles or on top of a coarse screen threshes the seeds. If a large volume of material is to be threshed, this is a very time- and energy-consuming operation. A simple threshing cylinder can be made by cutting a tire inner tube. The collected material is poured into the cut end of the tube, and the tube is rubbed by hand or foot until the seed is threshed clean. Another simple threshing device involves the use of two clay bricks or the halves of a single brick. This technique is especially applicable to seeds borne in capsules or nonsplitting pods. Place the fruits, capsules, and pods between the bricks and press with a grinding action. Leaving a few stems in the sample with the fruits insures ample spacing so the seeds are not crushed.

Mechanical Threshing

Hammer Mills

One of the first steps in mechanization is to use a hammer mill to rub the seeds loose (fig. 5). This is a most necessary operation for species where the fruit is so tough that hand rubbing is impossible. The novice seed processor must remember that hammer mills are designed to grind seeds for preparation of animal foodstuff. Improper use of a hammer mill will destroy the germinability of the seeds being processed.

The hammer mill utilizes many fingerlike hammers rotating inside a section of perforated metal cylinder. Seeds processed in the mill are subjected to a vigorous beating or rolling action between the hammers and perforated screen, which removes appendages and forces the seeds through the screen holes.

Results with the hammer mill depend on hammer speed, size of screen opening, feed rate, and condition of the collected material (Harmond et al. *1968*). A good speed for the hammer mill in this procedure is about 50 percent of that used in normal grinding operation. If the speed is too fast or the screen too small, the seeds will be mutilated, cracked, or grated. The feed should be regulated so that the mill is approximately full at all times. If the mill is operated only partly full, seeds will be damaged. A flow diagram for threshing bitterbrush seeds is provided in figure 6.

Scalping

Once the seeds are rubbed free, they are rough cleaned or scalped to remove the bulky foreign matter that will interfere with detailed cleaning. Stems, leaves, and trash not only interfere with fine cleaning but also contribute to high moisture content of temporarily stored samples.

Scalping for wildland seeds is usually done by hand screening. Again, we stress the principle of two screens: The first to let the seeds fall through and stop coarse trash, and the second to stop seeds and let fine trash pass through. For very small lots of seeds, kitchen strainers--such as those used for loose tea--serve very well for seed-cleaning screens.

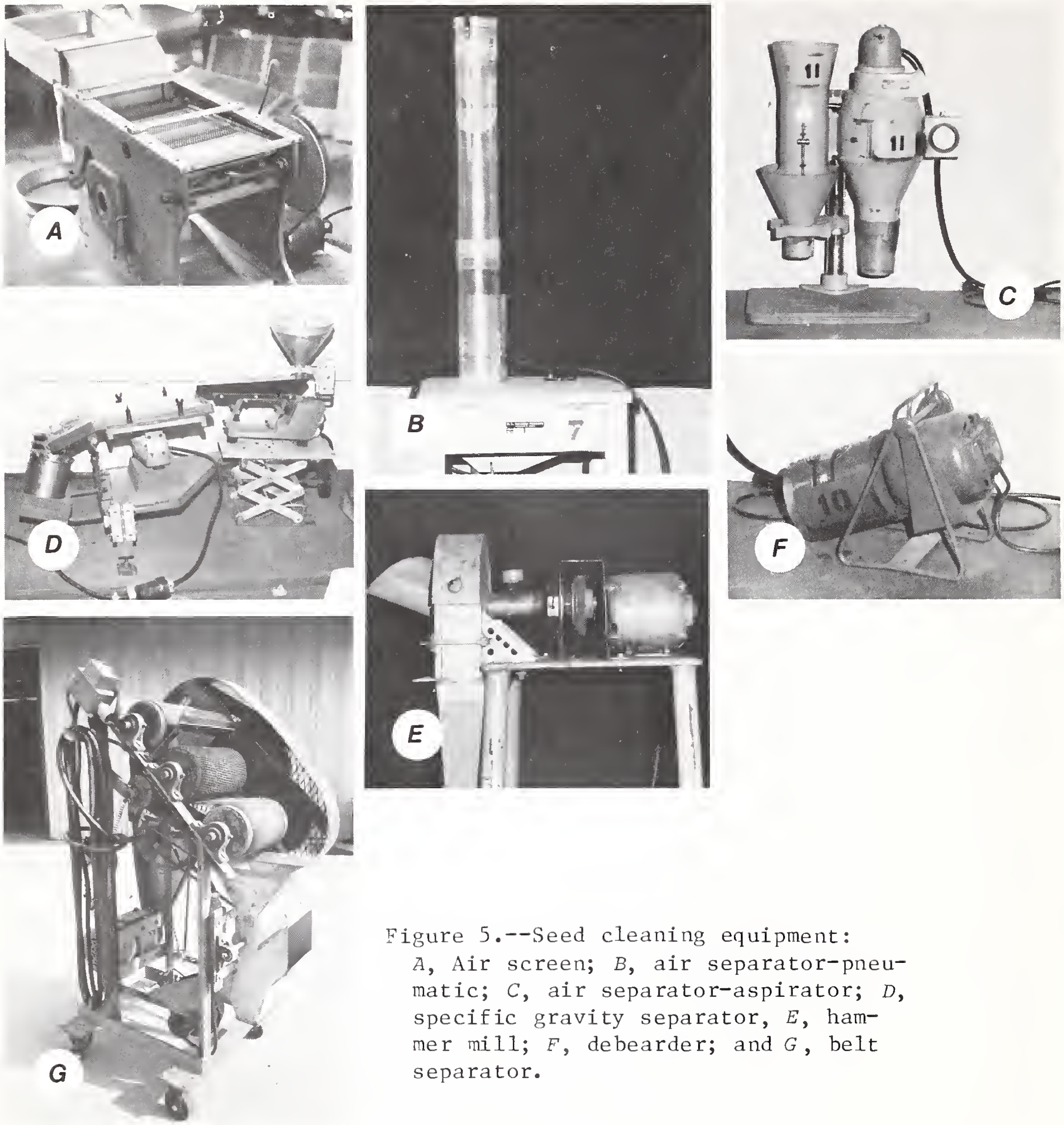


Figure 5.--Seed cleaning equipment: *A*, Air screen; *B*, air separator-pneumatic; *C*, air separator-aspirator; *D*, specific gravity separator, *E*, hammer mill; *F*, debearder; and *G*, belt separator.

Mechanical scalpers are made in many types, but generally consist of perforated metal screens that turn on a central shaft and are inclined slightly from the horizontal. Materials fed into the higher end tumble inside the reel until the seeds drop through the perforations. Large trash stays in the reel.

Debearders

Many seed lots can be cleaned directly after scalping, but for many grasses the awns or beards must be removed before the seeds can be cleaned. Debearding machines are commonly used to perform these functions and, in effect, to complete the threshing process.

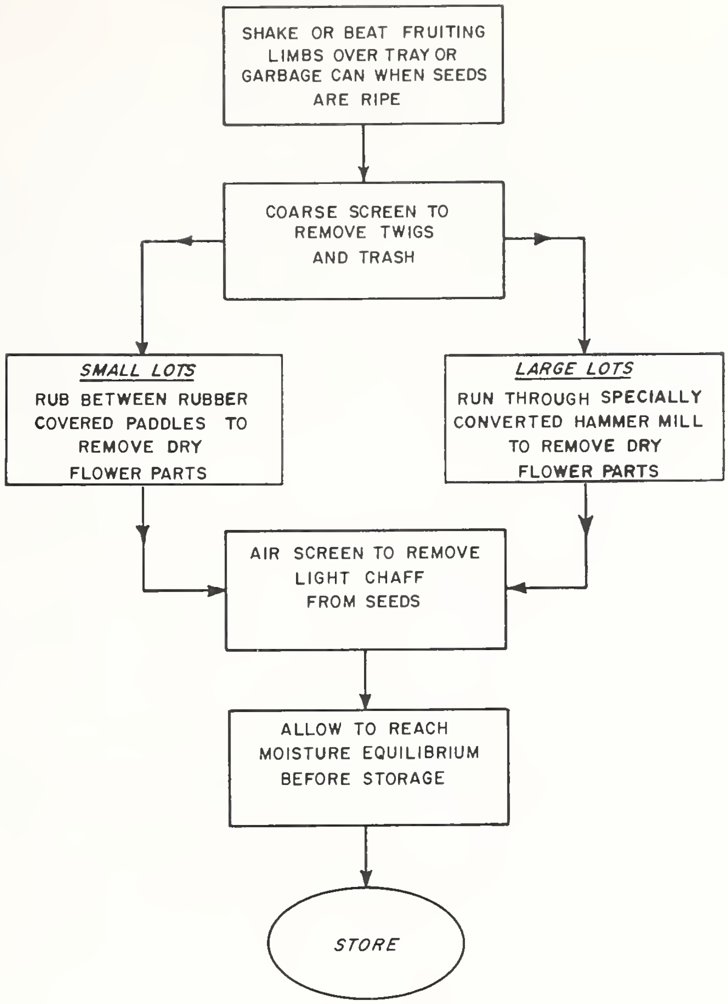


Figure 6.--Steps in collecting, threshing, and storing seeds of bitterbrush (*Purshia tridentata*).

The debearder consists of a horizontal beater that rotates inside a steel drum. The beater is made up of a shaft with projecting arms, which are pitched to move the seed mass through the drum. Stationary posts, adjustable for clearance with the arms, protrude inward from the drum and prevent the mass from rotating with the beater. In operation, this machine causes a vigorous rubbing of seeds against the arms, post, and each other. The time the seeds remain in the unit is varied by regulating a weighted discharge gate. The security of action is controlled by the exposure time, beater speed, and clearance between beater arms and post. Care must be taken not to damage the embryo portions of seeds. Debearding can also be done with a properly regulated hammer mill.

Second Phase Threshing

A threshing machine has various mechanical cleaning or separating operations in line after the threshing cylinder. In processing small quantities of seeds of wildland species, the next operation after threshing by hand or hammer mill and scalping is usually seed cleaning.

Handling Fleshy Fruits

Most of our discussion has applied to seeds that are dry at maturity or are borne in dry caryopses or achenes. Fleshy fruits, including the berries, drupes, pomes, and those with seeds enclosed in fleshy arils, require special processing, which involves macerating the flesh, separating the seeds with copious use of water, drying, and cleaning. Processing should be started soon after collection to avoid damaging, fermentation, or mummification.

Mummification can be desirable. Seeds of species with a fleshy covering are sometimes dried and planted with skins intact. After initial cleaning or washing, such fruits may be spread on sheeting or in trays and dried in the sun. The mummified fruit may contain germination inhibitors and provide a nutrient-rich substrate for micro-organisms during germination.

Small lots of fruit can be macerated by hand. The flesh is hand squeezed or mashed by a wooden block, rolling pin, or fruit press. Alternatively, flesh may be macerated by rubbing it against or through a screen. If the coarse screen is superimposed on a screen of a mesh sufficiently small to catch the seeds, a stream of water can be used to carry pulp away. Small-seeded fleshy fruits can be macerated in a blender. Care must be taken to use a speed and duration of treatment that do not damage the seeds (fig. 7).

Machines suitable for processing large quantities of fleshy fruits include feed grinders, concrete mixers, hammer mills, and macerators. Most of these machines only free the flesh from the seed, and the residue must be separated from the seed by a later cleaning. When the pulp is largely washed away, the seeds and fruit skins can be dried and the skin can be removed in an air separator.

Following maceration and separation, careful drying is necessary to avoid damage to the seeds.

SEED CLEANING AND SEPARATORS

Cleaning of seeds collected from plants growing on wildlands is often a hand operation. Mechanical seed cleaning equipment will greatly facilitate cleaning of even small lots of seed, and sometimes mechanical treatment is a necessary prerequisite for cleaning. Much of the information presented here on seed cleaning has been taken from Harmond et al. (*1968*).

In agriculture, much of the seed cleaning is done in the field before the crop is harvested. Good weed control practices minimize weed and other contaminant problems. In collecting seeds of wildland species, seldom can agronomic practices be applied to the stand producing the seeds.

Mechanical Seed Cleaners

The characteristics used in making separations of seeds and contaminants are size, shape, density, surface texture, terminal velocity, electrical conductivity, color, and resilience.

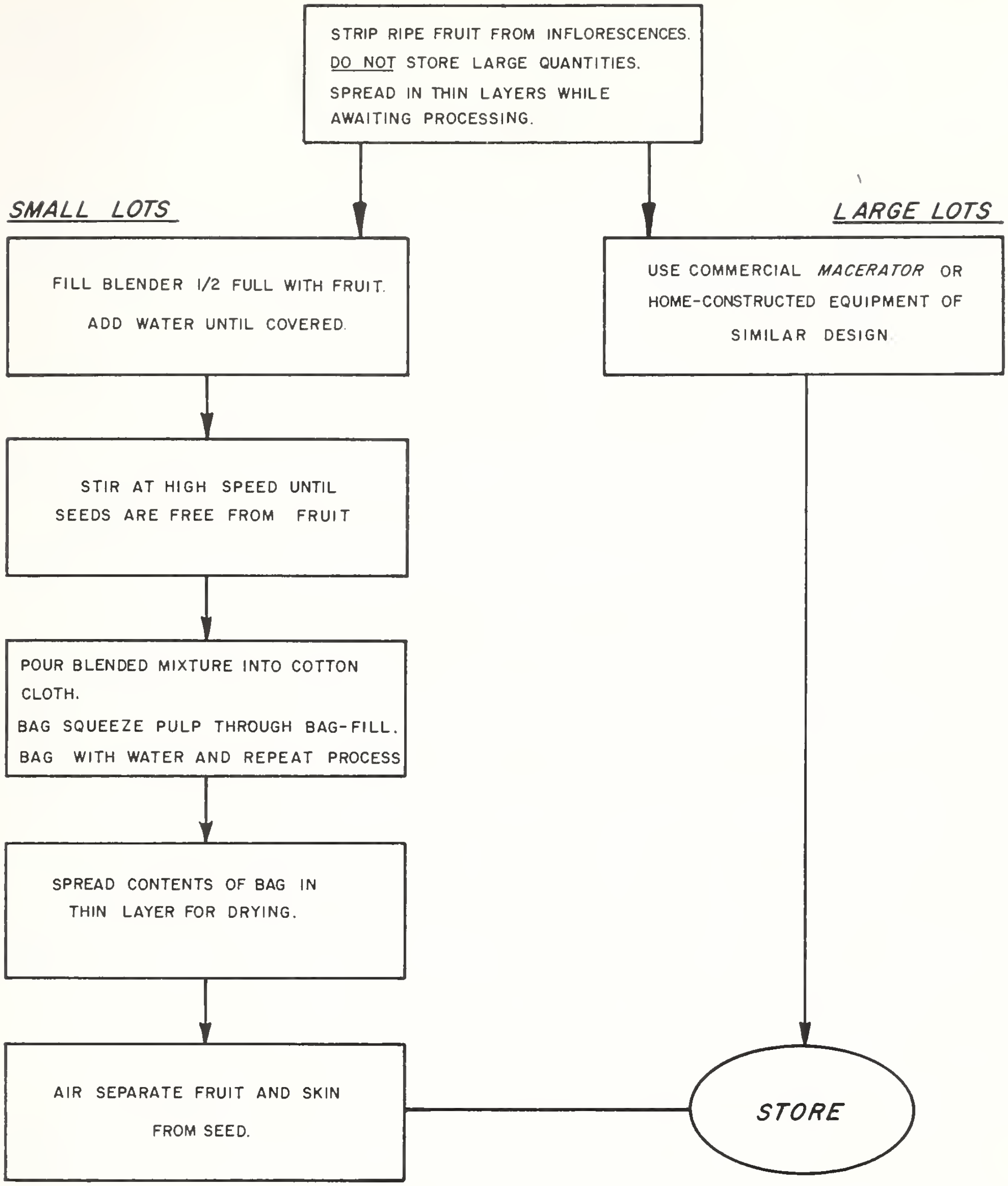


Figure 7.--Steps in collecting, macerating, and cleaning seeds of elderberry (*Sambucus glauca*).

Many types of seed-cleaning machines are available that exploit the above physical properties of seeds, either singly or in some combination. There are air-screen cleaners, specific gravity separators, pneumatic separators, velvet rolls, spirals, indent cylinders, indent disks, magnetic separators, electrostatic separators, vibrator separators, and others. A list of manufacturers of seed processing machines is available by writing: Agricultural Engineering, SEA-AR, U.S. Department of Agriculture, Beltsville, MD 20705. Ask for "Bibliography of Harvesting and Processing Forage-Crop Seed, 1949-1964" (Brandenburg *1968*).

The choice of machines used and their arrangement in processing depends primarily on the seeds being cleaned, the contaminants in the mixture, and the purity requirements that must be met.

Choice of Machines

The most widely used seed cleaning machine is the air-screen unit. It is the basic machine in commercial seed cleaning. It makes separations mainly on the basis of size, shape, and density.

Air-screen Cleaners

There are many makes, sizes, and models of air-screen cleaners available. With wildland seeds, the volume of seed is normally so small that a two-screen cleaner is adequate (fig. 5). Typically, with a small, two-screen cleaner, seeds flow by gravity from a hopper into an airstream, which removes light, chaffy material so the remaining seeds can be distributed uniformly over the top screen as follows:

1. The top screen scalps or removes large material.

2. The second screen allows dirt and fine wash to pass, but retains seeds.

The seeds are then passed through an airstream, which drops the plump, heavy seeds, but lifts and blows light seeds and chaff into the trash bin.

Screen numbering system.--The size of a round-hole screen is indicated by the diameter of its perforations. Perforations larger than 5.5/64ths of an inch are measured in 64ths. Therefore, a one-inch, round-hole screen is called a No. 64, a 1/2-inch screen is a No. 32, and so on. Screens smaller than 5.5/64ths of an inch are measured in fractions of an inch (that is, 1/13, 1/14, and so on). The smallest round-hole perforation commonly used in air-screen machines is a one twenty-fifth (0.04 inch).

Oblong-hole screens are measured in the same manner as round-hole screens except that two dimensions must be given. The hole width is indicated in 64ths of an inch; for example, 11 X 3/4 means openings eleven sixty-fourths of an inch wide and three-fourths of an inch long. In slotted screens smaller than 5.5/64 X 3/4, width is generally indicated in fractions of an inch; for example, 1/12 X 1/2.

Wire-mesh screens are designated according to the number of openings per inch in each direction. A 10 X 10 screen has 10 openings per inch across and 10 openings per inch down the screen. Such screens as 6 X 22 have openings that are rectangular in shape and are the wire-mesh equivalent of oblong-perforated or slotted screens. Triangular screens are usually measured by indicating the length of each side of the triangle in sixty-fourths of an inch.

Selected screens.--The two basic screens for cleaning round-shaped seeds are a round-hole top screen and a slotted bottom screen. The round-hole top

screen should be selected so as to drop the round seeds through the smallest hole possible, and retain anything larger. The seeds drop through the top screen onto the slotted bottom screen, which takes advantage of the seed shape and retains the round, good seeds while allowing broken crop seeds and many weed seeds and dirt to pass through.

The basic screens for lens-shaped seeds are usually a slotted top screen and a round-hole bottom screen. The lens-shaped seeds tend to turn on edge and drop through a slotted screen but lie flat and travel over a round-hole bottom screen, which will pass most other crop and weed seeds.

An experienced air screen operator can make unbelievable separations among seeds. If large amounts of seeds of wildland species are being collected, it may be worthwhile to get an experienced operator to air-screen the seeds. If no one is available or experienced with a given species, it will be necessary to experiment to find the correct selections.

If only handfuls of seeds of a given species are being collected, the screens from an air screen can be used for hand separations. At least one manufacturer of air screens sells screens mounted in a hardwood frame for hand cleaning.

Adjustments.--Besides the different types of screens used, the air-screen machines can be adjusted for rate of feed, airflow, oscillation of the screens, and screen pitch.

Generally, the grading or top screen should only be seven-eighths full. It is better to have a small section of the screen uncovered part of the time than to flood the screen occasionally.

Airflow is usually regulated by means of baffles in the air ducts. The airflow at the top of the duct is adjusted to blow out light, chaffy material and dust. Collections of seeds from wildlands that are threshed by hand are often very trashy. Seed collections of many wildland species will contain a high percentage of blank seeds where the fruit failed to fill. To remove these light seeds, the airflow at the bottom of the duct is regulated to a higher intensity to blow out all but the heavier seeds.

Oscillation of the screen is controlled by means of variable-speed pulleys and should be adjusted to keep the seed action "alive" over the screen. If too fast, the seeds hop across the screen and will not be separated. If too slow, the seeds have a tendency to slide. The pitch can be adjusted for each screen. The steeper the pitch, the faster the flow and the less time for separation.

Air Separator

Many different types of air separators are manufactured for seed processing. Some are called aspirators and others, pneumatic separators, but all use the movement of air to divide materials according to their terminal velocities (fig. 5).

Terminal velocity can be thought of as the velocity of a rising air current that will suspend a given particle. Although terminal velocity of a particle is a single characteristic, it is dependent on other properties--shape, size, surface texture, and density--all of which influence the particles' aerodynamic behavior in the airstream. If two different particles are fed into a rising airstream whose velocity is midway between the terminal velocities of the particles, one particle will rise and one will drop.

Two types of air separators are based on the location of the air movement unit. In the aspirator, a fan is placed at the discharge end of the air column where it induces a partial vacuum so that atmospheric pressure can force air through the system. In the pneumatic separator, the fan is at the intake end of the air column where it creates a pressure greater than atmospheric, which again forces air through the system. In both cases, air velocity through the machine can be adjusted by regulating the fan air intake. Seeds and contaminants with terminal velocities less than the air velocity through the units will be lifted. Materials with the same terminal velocity as the air will float, and objects with higher terminal velocities will fall against the airflow.

If only a small amount of seeds are to be cleaned, the air screen may be bypassed in favor of a seed blower. The South Dakota Seed Blower, or some modification, is usually found in most seed laboratories. This very simple machine consists of a motor-driven fan to supply air pressure and baffles in a vertical plastic cylinder for separation. Seeds are dropped into the vertical cylinder, and the air gate is opened until the airflow agitates seed in the cylinder. Light chaff will float out the open end of the cylinder. Various grades of seeds, based on weight, will be trapped in the baffles on the side of the cylinder. Stones and heavy trash will remain in the bottom. Ideally, the airflow is adjusted so no viable seeds are lost. This is a quick, visible method of cleaning small lots of seeds. In contrast to these small batch-type machines, there are large continous airflow separators in commercial cleaning operations. An excellent air separator for hand threshing is a hand-held hair drier with the heat turned off.

Specific Gravity Separators

Specific gravity separators classify material according to density or specific gravity. Component parts of the gravity separator are an airblast fan, an air-equalizing chamber, a perforated deck, a variable-speed eccentric, deck rocker arms, a feeding or metering device, a deck and adjustment, and a deck side tilt adjustment (fig. 5) (Harmond et al. *1968*). A mixture to be separated is metered at a uniform rate to the back of the deck. The slant of the deck and its oscillating motion move the seed over the deck. Air forced up through the porous deck from the equalizing chamber forms thousands of small jets, which cause the material to stratify into layers of different densities. In the air-stratified material, the light material floats and the heavy material is in contact with the deck. The oscillating motion of the deck walks the heavy material uphill nearly parallel to the discharge edge, and the air floats the light material downhill. All the material travels from the feed point on the deck to the discharge edge, a gradation of material takes place, ranging from light material on the lower side of the deck to heavy material on the upper side. By means of movable splitters, the discharge can be divided into any number of density fractions.

Harmond et al. (*1968*) illustrated the specific gravity separator's capability with crimson clover seeds contaminated with wild geranium seeds, dirt clods, and rocks. When the mixture is passed over a properly adjusted gravity separator, the geranium seeds and immature clover seeds will be discharged at the low side of the deck, the rock and heavy dirt clods at the upper side, and good crimson clover seeds in the middle.

The deck is the most important part of this machine. Various types of coverings are available to handle different types of seeds.

Other Seed Separators

If only a few hundred seeds of a plant species are to be cleaned, an efficient seed cleaner can be made from a sheet of newsprint. Fold the paper lengthwise and grasp each end at the folds. The seeds can be separated from the chaff and debris by gently inclining the paper while blowing on the material and juggling the paper. Although this may appear difficult, it is simple in practice to produce seeds sufficiently free of trash that only a final screening is required.

The commercial seed industry has a host of other types of seed separators. Usually, the collector of seeds of wildland species will not have the need or the volume of seeds to require these specialized machines. If large volumes of seeds are collected and cleaning problems arise, we again stress the value of Agriculture Handbook No. 354, "Mechanical Seed Cleaning and Handling" (Harmond et al. *1968*).

SEED STORAGE

Even while on the plant, seeds deteriorate. High moisture, high temperature, sunlight, and diseases can adversely affect seeds before harvest. As previously mentioned, if the seeds are held at a high moisture content awaiting cleaning, decline in viability will occur.

The following discussion of seed storage is drawn largely from Harrington (*1973*).

Importance of Moisture and Temperature

The two most important factors affecting seed longevity are seed moisture content and seed temperature. Harrington (*1973*) suggested two rules-of-thumb that express the influence of the moisture and temperature of the seeds of the rapidity of their deterioration:

1. Each 1-percent reduction in seed moisture doubles the life of the seeds.

2. Each 5°C reduction in seed temperature doubles the life of the seeds.

These rules give a quick grasp of the importance of low seed moisture and low temperature in preserving high seed germination.

Moisture Content

The above rules-of-thumb must be qualified. If the seed moisture content is high enough (over 30 percent), nondormant seeds will germinate. From about 18 to about 30 percent, heating due to micro-organisms will occur if oxygen is present, resulting in rapid death of the seeds. From about 10-percent seed moisture for oily seeds or about 13 to 18 percent for starchy seeds, storage fungi grow actively and destroy the seed embryo. Therefore, seeds should be dried as quickly as possible to below 14-percent seed moisture and should be kept below this moisture content at all times.

On the other hand, if seeds are dried below 4- to 5-percent seed moisture, deterioration is apparently somewhat faster than with 5- to 6-percent seed moisture.

Temperature

The rule-of-thumb for temperature is applicable down to at least 0°C. If the seed moisture is below 14 percent, no ice crystals form below the temperature at which a seed could freeze; so storage of dry seed at subzero temperatures should improve longevity. Unfortunately, most subzero stores have a high relative humidity, and after a period of storage the seeds gain moisture and ice crystals form. These crystals damage cells, causing loss in viability. If the seeds are first dried and then placed in moisture-proof containers, they will not regain moisture and should survive for a long period in subzero storage.

Even though cold storage (0° to 5°C) of seeds is desirable, unless the seeds are sealed in moisture-proof containers or the stored chamber is dehumidified, the storage relative humidity will be high. The seeds will gain moisture under these conditions, and when brought out to a higher temperature, they will deteriorate quickly.

Relative Humidity

We have already mentioned relative humidity as influencing seed storage. This fact is so important in seed storage that it is worth expanding on the nature of moisture in the air environment of seed storage.

Relative humidity of the air is a percentage measure of moisture in relation to the total weight of moisture that can be held at a specific temperature when the atmosphere is saturated. As temperature of the air increases, the weight of moisture that a given weight of air can hold also increases. If the absolute weight of moisture remains constant, relative humidity decreases on heating. Cooling increases the relative humidity, and, when it exceeds 100 percent, moisture will condense on the surface of the seeds. Since the moisture content of the seeds changes to remain in equilibrium with the ambient relative humidity, the seed moisture increases with cooling.

In a sealed container, there is a finite amount of moisture that can move into the seeds versus an infinite amount in open storage.

Drying Seeds

To dry seeds, the relative humidity of the air must be below equilibrium with seed moisture so there will be a moisture gradient from the seed to the air.

Lowering Relative Humidity

Seeds can be dried by unheated air only as long as the moisture gradient is from the seeds to the air. Unheated air will dry most freshly harvested seeds, but not to a safe moisture content. When the air is heated, the relative humidity is reduced and the moisture gradient from seed to air is increased; however, using air with too high a temperature can kill the seeds, especially if seed moisture is high. Even if the high-temperature drying does not immediately kill the seeds, it can cause injury with loss of vigor and shortened storage life. A temperature of 35°C is a maximal for many seeds.

Drying can be hastened as follows:

1. By using high temperatures.

2. By increasing the airflow. About 5 cm^3 of air per minute per cubic centimeter of seeds is the maximum economical airflow.

3. By allowing all sides of each seed to be exposed to the airflow as in a tumble drier or a baffled continous flow drier.

There is danger in too rapid drying. If the moisture gradient from the seed surface is steeper than the moisture gradient from the interior of the seed to the surface, there will be more rapid drying of the surface and cracking of tissue may occur. For some seeds, too rapid drying causes the outer cells to shrink and become impervious to moisture.

Removal of Moisture from the Air

The alternative to reducing the relative humidity in the air by heating is actually to remove the moisture from the air, thereby reducing the relative humidity. This can be done by refrigeration or by desiccation. Both of these methods have application to the commercial seed industry, but to collectors of wildland seeds the facilities may seldom be available.

Dry Storage

For proper storage, the seeds are dried first to the low moisture content desired. For one season's storage, the seed moisture content must be dried down

to at least equilibrium with 65-percent relative humidity. Methods of measuring relative humidity are discussed in a later section. For 2 to 3 years of storage, seeds should be dried to equilibrium with 45-percent relative humidity. For long-term storage, after packaging in moisture-proof containers, the seeds should be dried to equilibrium with 25-percent relative humidity or 5- to 6-percent moisture content.

Maintaining Seed in Dry Storage

After the seeds are dried to the desired moisture content, they must be kept at this level or the cost and benefit of the drying are lost. Maintaining the seed in a dry condition can be done in three different ways, although the principles are the same in each method.

1. The storage itself is made moisture proof and has dehumidification to maintain the desired relative humidity.

2. The seeds may be packaged in moisture-proof containers.

3. The seeds may be placed in gasketed containers, enclosing also an indicator desiccant.

Moisture-proof storage rooms.--There are specific standards for constructing moisture-proof storage rooms, but only the largest commercial collections of wildland seeds could justify the cost involved in construction. If the individual collector of wildland seeds has access to existing facilities, he should take advantage of the close-to-ideal storage conditions.

Moisture-proof containers.--Moisture-proof containers vary in capacity from aluminum foil laminated packets, tin cans, polyethylene (700 gage) bags, and aluminum foil laminated drums, to steel bins with gasketed lids.

The value of these containers as moisture-proof storage depends upon proper sealing.

Gasketed containers.--For many small lots, which must be opened from time to time, a desirable moisture-proof container is a steel box with a gasketed lid. For every 5 kilograms of seeds, 1 kg of dry indicator silica gel is added in a cloth bag. If, on frequent opening, the indicator color changes from blue to pink, the silica gel should be replaced by a dry silica gel, and the replaced silica gel should be reactivated in an oven. In a cool room (20°C or lower), this method of storage will keep seeds of most species without loss of germination capacity for several years.

Problems Arising From Dry Storage of Seeds

Although dry seeds maintain viability better in storage, there are two cautions to remember. First, dry seeds are more easily damaged by the handling that will occur in transport and planting. Second, seedlings do not emerge as quickly from initially dry seeds as from seeds of higher moisture content. Dry seeds require more water and longer time to imbibe and germinate. Conditioning to equilibrium with 65-percent relative humidity would minimize transport damage and increase rate of emergence.

Measurement of Seed Moisture

Since seed moisture is such an important aspect of the longevity of the seeds, the accurate measurement of the moisture of a seed lot becomes important. The simplest moisture test, and one used for centuries, is the bite test. If the seed feels rubbery when bitten, the moisture content is dangerously high.

The most exact moisture test employs the Karl Fischer reagent. The reagent combines stoichiometrically (the methodology and technology by which the quantities of reactants and products in chemical reaction are determined) with water, and the amount of reagent combined is measured colorimetrically. All other methods of measuring moisture use the Karl Fischer method as the standard for comparison; however, this method requires a chemist and is tedious and expensive.

Ovendrying Test

The International Seed Testing Association approves oven methods of moisture determination of either 105°C for 24 hours or 130° for 1 hour. Depending on the type of seed, the oil distillation method may be required. These methods can be accurate to ±0.1-percent seed moisture.

Infrared Balances

There are many types and models of infrared balances and electrical conductivity measures for determination of seed moisture. Some are portable enough for field determination. Check manufacturers' standards for limits of accuracy, and be sure to calibrate against one of the standard methods for determining seed moisture content.

Electronic sensors are available for determining relative humidity. These are especially useful in small containers where standard psychrometers are difficult to operate. If the seeds have reached equilibrium with the relative humidity of the storage, measurement of relative humidity is a better measure of the storability of the seeds than seed moisture content. Many factors influencing seed storability, such as aging of seeds, fungal growth, and insect activity, are more directly correlated with relative humidity than seed moisture.

SEED STORAGE INSECTS

Many insects that attack stored seeds were originally from the Tropics (Storey et al. *1979*). They spread and adapted to colder climates by living in handmade food storage shelters. Because stored-seed insects cannot remain active at low temperatures, their potential for development and damage is much greater in warm climates.

Most insect pests of stored seeds have a short period from egg to adult, their reproduction rate is high, and their adult lifespan is long. Temperature

and moisture of the stored seeds influence the life cycles of the insect pest. Most stored-seed insects require temperatures of more than 15°C to develop damaging populations (Storey et al. *1979*).

Stored-seed insects obtain water primarily from the seeds themselves. If the moisture content of the seed is low, generally less than 10 percent, the insects must obtain water by breaking down the grain components or by using their own energy reserves. Under these conditions, fewer insects survive (Storey et al. *1979*). Properly applying these two natural factors--temperature and moisture--is fundamental to providing proper protection from storage insects.

When freshly harvested seeds are ready for storage, a few obvious safeguards can be employed. Do not store fresh seeds in contaminated containers. If small containers are used, cleaning before storage is simple. If large, bulk storage is used, cleaning is more difficult. Make sure no remnant seed from a previous year's storage is left in the bin in corners or cracks. Some insecticides are available for treating seed storage areas (see "Insect Control in Farm-Stored Grain," Storey et al. *1979*).

To help identify the kinds of pests that damage stored seeds, Agriculture Handbook No. 500, "Stored-Grain Insects," is available for sale from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Once you discover that storage insects have contaminated your supply of wildland seeds, your choices of action are limited. Control of the insects probably requires fumigation. Because fumigant chemicals are highly toxic and hazardous to use, they are classified as restricted pesticides. Special training and certification are required before these material can be purchased or applied. Persons desiring certification should contact their local Cooperative Extension Service specialists or State Board of Agriculture for further information about restricted-use pesticides. Because seeds of wildland species are not of major economic importance, there may not be a pesticide registered for use on the specific species contaminated. It is much better to avoid the problem with clean storage containers and proper moisture and temperatures for storage.

SEED GERMINATION

Once the collector of the seeds of wildland species has mastered the problems of timing collections, threshing, cleaning, and storage, propagation is possible if the seeds will germinate. Some private and government laboratories will test the germination of submitted seed lots. These laboratories are largely geared toward seeds of agronomic species and for conducting germination tests as prescribed by either national or international standards of testing seeds. Unfortunately, for most wildland species, there are no standards for conducting germination tests. If the seeds of the desired wildland species are dormant, the collector may learn little more than that fact unless a sympathetic seed technologist has the time to experiment with the seed lot.

If the collector wants to know if certain seeds will germinate or what kind of dormancy is limiting their germination, he or she is faced with solving the problem alone.

Not all wildland seed collectors have the time or inclination for such endeavors, but a great deal can be learned from some rather simple tests. Good basic reference books for germination technology are "Principles of Seed Science and Technology" (Copeland *1976*) and "Sexual Propagation" (Hartman and Kester *1968*).

There are publications that provide useful tests for germination of some native plant species (Emery *1964* , Mirov and Kraebel *1939*). To conduct these tests, some basic items of germination equipment are necessary.

Germination Testing Equipment

Petri dishes have been the standard item in which to conduct germination tests. Disposable plastic petri dishes are cheap and available from biological supply houses. Many commercial seed laboratories have switched to plastic germination boxes, which are easier to stack and to fit with germination paper than the circular petri dishes.

Besides a container, a substrate to maintain moisture is necessary. Blotter, filter paper, or commercial germination paper is used. Paper toweling may contain germicides which limit seed germination. Besides paper, sterile sand, vermiculite, perlite, or mixtures of all three can serve as a germination substrate. Commmercial seed-testing toweling or indented pads to hold a given number of seeds are available from firms that service grain elevator and seed testing laboratories.

For seeds that have published germination standards, the type of substrate is specified. For most wildland species, trial and error must suffice.

Germinators

The purpose of a germinator is to provide an environment conducive to seed germination. Generally, this consists of a specific temperature with a free moisture supplying substrate and a near-saturated relative humidity around the seeds. In addition, alternating diurnal temperature regimes or light of specific quality may be necessary.

The most common type of commercial germinators available are designed to maintain a temperature higher than ambient and to maintain a nearly saturated relative humidity from a free water surface. Much more expensive models of commercial germinators provide refrigeration for temperatures lower than the ambient. At additional expense, lights are available with automatic controls for diurnal temperature fluctuation and photoperiods.

Seeds of many wildland species germinate under cool to cold conditions, making a refrigerated germinator important. For the collector who cannot invest in an expensive germinator, an old refrigerator can be easily modified to serve the same purpose. Generally, pre-1960 refrigerators that have functioning compressors are better for this purpose than more modern models.

Temperatures can be varied in these old refrigerator germinators by adjusting the temperature control and choosing different shelf locations. It is not difficult to construct a lighted germinator from an old refrigerator. A cool-white fluorescent light source is necessary for germination tests of seeds requiring light. If a small enough fixture is found, it can be rigged inside the refrigerator. High light intensities are not required. An intensity of at least 4.6 lux (50 footcandles), and preferably 7 to 11.6 lux (75 to 125 footcandles) should be provided. Fluorescent tubes of 20 to 25 watts will suffice for light source.

Fungicides

If seeds are germinated at moderate to high incubation temperatures, microorganisms often will colonize the germination substrate and seeds. Fungicides can be added, but it is often better to avoid the problem by incubating the seeds at cooler temperatures or by careful sanitation. Make sure petri dishes, germination pads, and working areas are clean. Seeds can be partially surface sterilized by pouring boiling or near-boiling water over the seeds while they are held in a screen or by rinsing the seeds with a 0.01-percent solution of hydrogen peroxide. If a fungicide must be used, care must be taken in determining the proper concentration to insure germination is not lowered or inhibited. Groups of rolled germination blotters or dishes may be kept in a large plastic bag, which will minimize infections and help maintain high humidity between inspections.

Testing Germination

Initial Test

Once seeds of the desired species are collected and cleaned, germination tests can be conducted.

Afterripening.--The seeds of many species will not germinate or have limited germination at maturity. Gradually, over time and rather independent of postharvest storage, this type of seed becomes germinable. The postharvest period of transitory dormancy is called an afterripening requirement. The length of this afterripening period varies greatly among species. For many species, one month or less after maturity is sufficient.

Several species of wildland plants have temperature-related afterripening requirements. Generally, seeds of this type will germinate at low temperatures, but not at moderate or high temperatures until afterripening requirements are satisfied. In order to know if seeds of particular species have afterripening requirements, it is necessary to make repeated germination tests starting soon after maturity and to continue making them for 6 months.

Low incubation temperatures are more likely to produce germination than higher incubation temperature for seeds with afterripening requirements. As previously mentioned, the low temperatures also reduce growth of micro-organisms.

While conducting initial germination tests to determine if afterripening requirements exist, other observations can be made to aid in determining the mode of germination or dormancy.

Hard seed.--One of these important observations is to determine if the seeds imbibe moisture. Imbibition is noted by observing swelling and softening of the incubated seeds. If the test seeds remain hard and dense, failure to germinate may be due to a hard seed coat that limits imbibition of moisture. This is especially common among small-seeded legumes.

If seeds fail to germinate with 6 months afterripening or fail to imbibe moisture with initial test, some form of germination enhancement will be required.

Germination Enhancement

If the test species imbibes water but does not germinate, moist stratification is the next logical step. If the seed does not imbibe moisture, a scarification treatment is necessary.

Seed scarification.--The purpose of seed scarification is simply to break the impermeable seed coat and allow entrance of moisture. Scarification can be accomplished through mechanical abrasion or soaking in acid. Concentrated sulphuric acid is commonly used to scarify seeds. The length of time required for scarification must be determined by experimentation. Length of treatment may vary from seconds to 6 hours, depending on the species being treated. Some particularly woody fruits may require 24-hour treatments in acid. Within narrower limits, the optimum duration of scarification treatment will vary among lots of seed of the same species. After acid treatments, seeds should be neutralized and washed. The key to either mechanical or acid scarification is to avoid damage to the embryo. Remember, strong acids are dangerous and should be handled with care.

For very small lots of seed, careful rubbing on fine sandpaper may be sufficient to abrade the hard seedcoat. Mechanically threshed and cleaned seeds usually require less scarification than hard-threshed seeds of the same species because of the damage inherent by mechanical handling of seeds.

The maternal environment in which seeds are produced influences the amount of hard seeds. If a hard-seeded wildland species is grown under irrigation in a favorable environment, the amount of hard seeds may be reduced. Occasionally, hard-seeded species will imbibe moisture after scarification, but still fail to germinate.

Seed stratification.--If the test seed imbibes water either before or after scarification but fails to germinate, stratification is a logical next step.

Cold-moist stratification is the type most commonly used. The embryo of many seeds fails to germinate because of lack of oxygen diffusion through the seedcoat. At cold temperatures, more oxygen is soluble in water and the oxygen requirements of the embryo are lower. Cold-moist stratification corresponds to overwintering under snow cover in a field seedbed.

Stratification requirements for seeds vary greatly among species both in optimum temperature and duration. Generally, temperatures in the range from 2° to 5°C are best. Time required for stratification varies from 2 weeks to several months.

One should not assume that a one-month stratification requirement will be satisfied by fall planting. The stratification requirement will be met if temperatures are not excessively cold, if the seeds remain moist, but not saturated, and if the cool-moist period lasts for a month without interruption. Often the cool-moist period is in the spring when the seeds should have already germinated in order to survive the summer drought. Stratified seeds cannot be seeded in the fall without risking germination and frost damage or freezing death.

Plastic bags are useful in stratification treatment. The seeds are placed in the bags with moist sand or vermiculite and stored at low temperatures, usually 2°, 5°, or 10°C, until the afterripening requirement is satisfied. The seeds can be placed in a cloth bag to aid in recovery from the plastic bags. A variation of this method is to fill the stratification bags with activated charcoal. Activated charcoal stratification is the only effective method to obtain germination of some species.

A variation of the stratification procedure is to stratify seeds in a cold water bath where the oxygen content of the liquid is kept near saturation by forcing compressed air through the liquid. This method has given spectacular results with seeds of species that normally do not respond or respond poorly to stratification. The specific length of stratification must be determined by trial and error.

Besides cool-moist stratification, seeds of some species require warm-moist stratification or a combination of warm-moist followed by cool-moist stratification. Such combinations of requirements are very difficult to determine without considerable experimentation.

Occasionally, seeds require a very specific stratification temperature, such as 2°C with 0° or 5° not satisfying the stratification requirements. Again, this type of requirement necessitates a great deal of experimentation.

Moist heat.--A sometimes successful alternative to scarification of hard seeds and an occasionally valuable enhancement treatment for seeds that do not respond to stratification involves immersion in hot water. An effective treatment consists of dropping seeds into boiling water, immediately removing the container from the heat, and allowing the seeds to steep in the hot but cooling water. Duration of effective treatment may be from a few seconds to 2 hours, depending on the seed or fruit. The seeds of several species of *Ceanothus* respond to hot water treatments.

Water soluble inhibitors.--Soluble inhibitors can be washed from seeds with running tapwater. Water cold enough to inhibit germination is useful in that after the leaching process the seeds can be planted without any damage to partially emerged radicles.

Water soluble germination inhibitors can be removed by planting seeds in containers of damp sand and placing the containers on mist benches. The amount and incidence of mist should not be excessive, but must keep the sand damp.

For some species, especially some grasses, the germination inhibitor can be physically removed by removing awns or other appendages of the caryopses. Remnant flower parts on achenes may contain germination inhibitors, such as in the case of bitterbrush. Relatively simple mechanical processing eliminates this type of germination inhibitor once the cause of dormancy is recognized.

Nonwater soluble inhibitors.--Germination inhibitors that cannot be removed with washing or boiling can be removed with organic solvents. Soaking in acetone or methyl chloride can enhance germination of dormant seeds. This type of treatment should not be construed as simply washing away an inhibitor. These chemical treatments probably involve complex reactions that alter permeability of seedcoats or the biochemical status of the embryo itself. These and other chemical treatments for germination enhancement may influence oxidative processes in seed germination. For a discussion of these processes, see Heydecker (*1973*).

Hydrogen peroxide.--Seeds of several species, especially members of the rose family, have their germination enhanced by soaking in hydrogen solutions. Dramatic germination enhancement has been obtained with seeds of bitterbrush (*Purshia tridentata*) (Everett and Meeuwig *1975*) and curlleaf mountain mahogany (*Cercocarpus ledifolius* Nutt.) (J. A. Young, unpublished research). A wide range of concentrations is effective from 1 to 30 percent. Generally, the higher the concentration, the shorter the soaking time, but the greater the risk of damaging the seed. Hydrogen peroxide is a very reactive chemical. Concentrations greater than 3 percent are particularly dangerous to handle.

Light.--If after washing, stratification, scarification, and boiling, seeds still fail to germinate, the effect of light intensity, duration, and quality should be investigated. In actual testing sequence, the seed lot should be subdivided at the beginning, and all of the above procedures should be conducted at the same time. Often, a sufficient quantity of seeds of wildland species may be lacking, and a stepwise procedure may be followed to conserve seeds in hopes that the key to germination will be found before all the steps in the experimental procedure are necessary.

To determine if seeds have a positive germination response to light, imbibed seeds should be exposed to cool-white fluorescent light for 8 out of every 24 hours. As we previously mentioned, illumination of 75 to 125 footcandles is adequate. Occasionally, longer diurnal photoperiods may be more effective in promoting germination.

Seeds of many species germinate after exposure to red light and are inhibited by exposure to far red light. For a discussion of light quality and germination, see Mitrakos and Shropshire (*1971*). This type of germination enhancement requires light filters, darkrooms, and light-proof containers. Generally, exposure to incandescent light should be avoided and fluorescent light should be provided.

Sulphydryl compounds.--Many sulphydryl compounds have a markedly stimulatory effect on dormant seeds. The most well-known agent of this class is thiourea. For western wildland species, the classical example of the use of thiourea is for breaking dormancy of bitterbrush seeds (Peterson *1957*). The seeds are soaked in a 3-percent thiourea solution, then dried before rewetting for germination. *Thiourea is potentially a very dangerous chemical and may constitute a hazard to users.*

Ethylene.--Ethylene has long been known to elicit a wide range of physiological responses in plants. For numerous species, ethylene can be used to enhance germination as a gas or with the chemical ethephon,[4] which produces ethylene when added to the germination substrate.

Secondary Germination Enhancement

We have not discussed all of the possible treatments to enhance germination of dormant seeds, but have presented the most often used and successful treatments. Often, application of the primary treatments will result in some germination of previously completely dormant seeds, but this level of germination will be so low that opportunities for propagation are still quite limited. Several combinations of treatments enhance germination when applied with a primary dormancy-breaking treatment.

Potassium nitrate.--The germination of seeds of many species is influenced by the presence of nitrate ions. Potassium nitrate is widely used for a source of nitrate ion enrichment. The addition of potassium nitrate should probably be ranked as a primary method of germination enhancement, but often it is used to additionally increase germination after scarification, stratification, or light treatment. Standard germination standards for seeds of many agronomic species require the addition of a 0.2-percent solution of potassium nitrate to the substrate during germination or as a part of pregermination chilling treatments. Lower concentrations of potassium nitrate may be more effective for some species.

Gibberellic acid.--The mode of action of gibberellic acid in seed germination is not known, but very low concentrations of this growth regulator can greatly enhance germination. Concentrations of from 1 to 250 parts per million (p/m) are commonly used in germination enhancement. Combinations of gibberellic acid and potassium nitrate are often more effective than either material alone. Both of these materials can be obtained from chemical supply houses. The potassium nitrate is more easily obtained than gibberellin.

A good balance is needed for preparing the minute concentrations of gibberellic acid. A solution with a concentration of 1 p/m of gibberellic acid consists of 0.001 grams of gibberellic acid dissolved in 1,000 milliliters of water. Gibberellic acid is sold as a 10-percent active-ingredient preparation, which makes the weighing simpler. One alternative is to prepare higher concentrations than needed and dilute to the desired concentration. For example, 1,000 p/m would be 1 g in 1,000 ml; however, gibberellic acid is relatively expensive and breaks down very rapidly under warm temperatures.

Again, we have not exhausted all of the chemicals that have been used to promote germination, but have suggested those proven to be most useful. The various alternatives for germination enhancement are shown diagrammatically in figure 8.

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[4](2-chloroethyl)phosphonic acid.

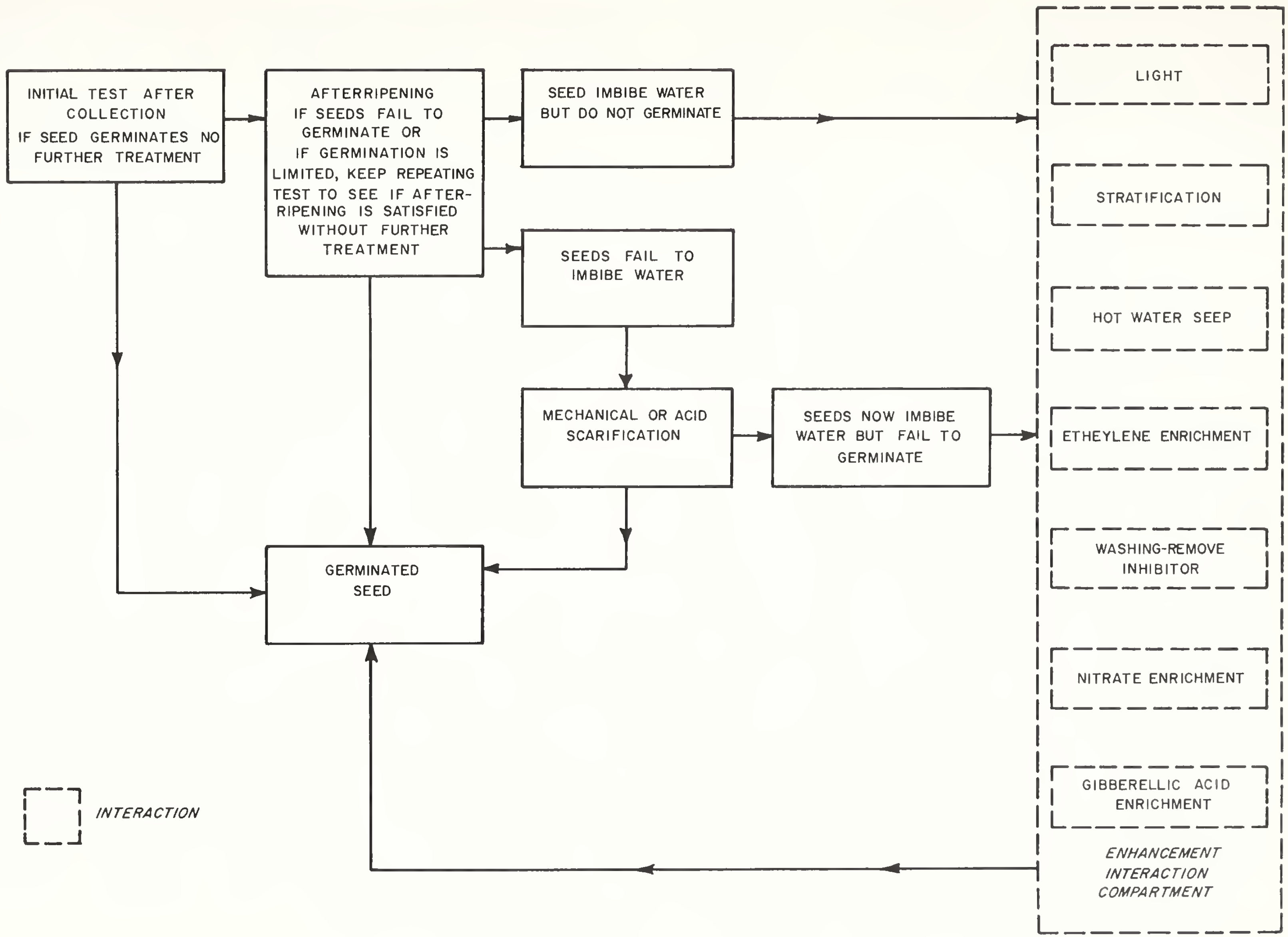

Figure 8.--Steps in enhancing germination of seeds of wildland species for which no germination standards exist.

Viability Test

Seed analysts have searched for a rapid and reliable test for seed viability that would eliminate the long germination test sequence for dormant seeds. Many methods of estimating viability have been examined, but embryo excision and tetrazolium staining are generally used and recognized in official seed testing procedures.

Cutting test.--Seeds are cut open, and those with fully grown, firm, undamaged, healthy looking tissue with the proper color are judged viable. Judged as nonviable are seeds with milky, unfirm, moldy, decayed, shriveled, or rancid-smelling embryos and abortive seeds that have no embryo. The problem with this cutting test is that extremely small or very vitreous seeds are impossible to cut without crushing the embryo.

Tetrazolium test.--Biochemical staining tests have been developed that visibly stain viable seeds. The commonly used test is the tetrazolium method. The Association of Official Seed Analysts has a handbook that should be followed when conducting tetrazolium tests (Grabe *1970*).

Tetrazolium tests are only definitive when standards have been developed for interpreting the results. Just because seed tissue stains red with tetrazolium does not mean the seed will germinate when factors causing dormancy are overcome.

LABELING SEED LOTS

The information required on a seed tag varies among States, but a generalized label requires the following:

1. Common name of species and subspecies or variety, if appropriate.

2. Scientific name of the genus, species, and subspecies or variety, if appropriate.

3. Lot number or other identification.

4. The origin of the seeds. For seeds collected from predominantly indigenous stands, information regarding the area of collecting by latitude and longitude, geographic description, or political subdivision such as State and county are marked on the label.

5. The upper and lower limits of elevations within which the seeds were collected.

6. The purity of the seeds as a percentage of pure seeds by weight.

7. For species for which standard germination testing procedures are prescribed by State regulations, the germination percentage, percentage of firm ungerminated seeds, and the date of the test by month and year are marked on the label. For freshly harvested seeds, the label may say

"test in process." For seeds being transported to a consumer, the label may say "contract seed *not for resale* and subjected to test to be arranged." For species for which standard germination testing procedures have not been prescribed, only the calendar year in which the seed collected is required. Unfortunately, most wildland species do not have prescribed methods established for seed germination.

8. The name and address of the person who labeled the seeds or who sells or offers them for sale.

9. For specific label requirements, check with the State Department of Agriculture to see which seeds are being shipped.

Obviously, the label on a bag of seeds can be a very informative document. Considering the very high cost of the seeds of many wildland species, it is important to insist on properly labeled seeds and to read the label before purchasing.

SPECIFICATIONS FOR SEED QUALITY

Problems of satisfying quality often arise when selling seed. Minimums of purity and germination are commonly stated when buying crop seeds. Workable minimums are available based on years of experience, and values are quite high as the result of crop improvement and cultural practices.

Wildland plant seed lots are different. They may have much lower germination rates than those of agronomic seeds because of the limited moisture conditions under which they are grown and may be less pure because of difficulties in cleaning. Problems are created when unrealistically high values of purity and germination are specified.

One way of avoiding this dilemma is to specify pure live seed (PLS). Instead of specifying 12 kg/ha of a species minimum germination of 85 percent and minimum purity of 98 percent it would be simpler to specify 10 kg/ha PLS. This can amount to the same number of live seeds per unit area but gives the contract writer, seed dealer, and seeding contractor some latitude. Using the above example (seed of germination 85 percent, purity 98 percent, and specifications of 10 kg/ha), one would still require 12 kg of seed per hectare or

$$\frac{10}{0.85 \times 0.98} = 12.$$

If the only seed available were of 70-percent germination and 98-percent purity, however, the contract could still be fulfilled by seeding 14.6 kg/ha or

$$\frac{10}{0.70 \times 0.98} = 14.6.$$

Wildland plants might be as low as 30-percent germination and 30-percent purity. Seeding 10 kg/ha would require 111 kg/ha or

$$\frac{10}{0.30 \times 0.30} = 111.$$

The extra seed volume created by the last example might be a problem in the drilled or aerial seedings commonly used in agriculture; however, many wildland seedings are done with hydraulic planters (hydroseeding), in which the extra volume would be a welcome addition to the mulch normally specified. This would help avoid excessive cleaning, which results in extra cost and the possibility of damaging or losing seed.

ENDANGERED AND THREATENED PLANT SPECIES

Regulations governing interstate and foreign commerce and import and export of endangered and threatened plant species became effective July 25, 1977. The regulations establish a flexible system to allow legitimate commerce to continue in jeopardized plant species while protecting those plants remaining in the wild. Under the Endangered Species Act, it is illegal--except by permit--to import or export, or to sell, offer for sale, deliver, receive, carry, transport, or ship in interstate, or foreign commerce, listed plants. To obtain copies of the regulations and the up-to-date list of species contact the Federal Wildlife Permit Office, U.S. Fish and Wildlife Service, Washington, D.C. 20240.

The Office of Endangered Species of the U.S. Fish and Wildlife Service is a good source for the names of publications with local and regional floras of endangered, threatened, and rare vascular plants. Check with the Fish and Wildlife Service Regional offices in Honolulu, Hawaii; Portland, Oreg.; Denver, Colo.; Albuquerque, N. Mex.; Twin Cities, Minn.; Boston, Mass.; and Atlanta, Ga. The plant taxonomist at your local university is another good source for rare plant information.

In some States, there may be applicable State laws and regulations for intrastate commerce in native plants. The important point is to check and make sure the species you are collecting are not endangered, or rare; or if you want to work with the rare and endangered species, get the required permits and follow the regulations.

PROPAGATION

Direct Seeding

The least expensive method of propagating seeds of wildland species is by direct seeding (Chan et al. *1977*). A large amount of literature exists concerning seeding of wildlands, and review of this material is beyond the scope of this publication.

The degree of seeding success will largely depend on how well the seedbed is prepared and the care with which the germinable seeds are placed in the seedbed.

Good soil contact with the seeds is essential for germination. The seeds must be buried in the seedbed, but not too deep for rapid emergence. Burial to a depth two to three times the diameter of the seed is a good rule-of-thumb.

The number of planted germinable seeds that actually germinate is dependent on the potential of the seedbed to support germination. This may sound like doubletalk, but it is a very important point to consider in seeding. A common mistake is to assume that doubling the seeding rate will increase the chances of seedling establishment. This may be true if the potential of the seedbed can be modified by furrowing or pitting to create microtopographies that produce desirable environments for germination. The addition of mulch also increases the potential of seedbeds to support seed germination. Ash accumulations--after wildland vegetation or slash piles are burned--are often used as seedbeds, because the ash provides and opportunity for seed coverage in a nutrient-rich seedbed; however, some ash seedbeds may be water repellent. In seeding wildlands, it is sometimes possible and desirable to take advantage of natural mulches, such as scattered slash, to enhance the germination potential of seedbeds.

When seeding wildlands, drill the seeds if possible. There are many different types of drills, but they have similar basic components. Seeds are stored in a box from which they are metered at the desired seeding rate to a seed tube, which conveys the seed to an opener. The opener makes an opening in the seedbed into which the seed drops. Following the opener, some form of wheel or drag closes the opening and covers the seed with soil.

If the seedbed is not too rocky, rough or trashy standard grain drills, such as those used on farmlands, can be used. Grain drills often use double disk openers that are followed by press wheels to close and firm the seedbed. Grain drills have the advantage of being readily available in most rural areas. The major disadvantage is that they are not designed to withstand the rigors of wildlands. Slow operating speeds and careful maintenance are necessary for grain drills to withstand rocky ground or rough terrain.

The ultimate in drills for small seeded species is the grass-small-seeded legume drill. This drill has one or two seed box spreaders mounted between cultipackers. The first cultipacker smooths the seedbed while creating small furrows. The seed is broadcast onto the ground behind the first cultipacker. The second offset cultipacker fills in the original furrows covering the seeds. Obviously, this drill is restricted to rock-free, well-prepared seedbeds.

Several models of pasture drills are available. These drills are designed to drill seeds directly into stubble or sod without previous tillage. The openers consist of notched coulters or chisels to penetrate the seedbed. The coulters are used on trashy seedbeds. Press-wheels firm the soil over the seeds. These drills are usually more sturdily contructed than most grain drills; however, pasture drills will not withstand large, fixed rocks, logs, or rugged terrain seedbeds.

The rangeland drill was specifically designed for wildlands. Each opener is independently suspended so it can ride over obstructions in the seedbed. The general construction of the drill is very heavy duty. It features large wheels and a high clearance frame. Besides the standard disk opener, trailing arm openers and heavier furrowing arms are available. A major disadvantage of this

drill is that seed coverage is attempted with chain or pipe drags. A second disadvantage of the rangeland drill is its limited availability. The high cost (over $10,000) precludes the use of this drill except by public land management agencies and large-scale revegetation contractors. Special care must be taken in transporting rangeland drills because they are massive and heavy. Helpful tips and drawings of useful equipment for transporting the rangeland drill are offered by Spencer et al. (1979). Despite its drawbacks, the rangeland drill is the only drill that can be operated on many wildland seeding locations.

No matter which type of drill is used for seeding wildlands, it must be calibrated. The seeds are usually metered from the bottom of the seed box through a variable opening. A simple way to calibrate the drill is to fill the box with seeds, remove a seedtube from an opener, and secure a plastic bag around the end of the tube with a rubberband or tape. As the drill is towed a measured distance, the seeds per linear unit of row distance can easily be determined. For example, the desired seeding rate for wheatgrasses on sagebrush rangelands is usually two seeds per inch.

Many drills have two seed boxes, so small seeds, such as small-seeded legumes, can be metered from a separate system. Fluffy, low density seeds present a special and difficult problem. Drills with larger openings, special agitation systems, and metering drives have been developed for native grass seeds that are very fluffy. When mixtures are drilled from the same box, continued agitation may lead to differential settling of seeds of varying densities in the drill box. When seeds of shrub species are drilled by themselves, it is difficult to close the drill box opening to obtain the desired seed rate and still allow the seeds to pass through the opening. Usually, some form of inert extender is mixed with the seeds to make metering simpler. Vermiculite or rice hulls have been used as inert extenders.

If seed treatments to enhance germination are necessary, the problems with direct seeding are increased and drilling is usually impossible. The treatments often leave a moist, imbibed seed that will not pass through seed drilling equipment and must be placed in a seedbed environment conducive to germination.

Hydroseeding offers the opportunity to both improve seedbed potential by mulching and to safely handle imbibed seeds; however, it does not provide the seed coverage necessary for the establishment of many wildland species under non-irrigated conditions.

Hand-operated wheel planters, originally designed for vegetable planting, are available for seeding small areas. The metering system on these planters is traction driven with the rate of seeding controlled by the size of openings in interchangeable plates. The opener is a fixed shoe with inverse wings to draw soil back over the seeds and a press wheel to firm the seedbed. Operating such seeders is physically demanding and very frustrating if rocks or sticks are present in the seedbed. For spot seeding at intervals, dibble stick planters are available. Commercial models include a mechanism to drop a predetermined amount of seeds after the dibble is driven into the seedbed. Any form of hand planting is labor intensive and subsequently costly.

A good source of information on planting equipment, including a list of suppliers, is the Revegetation Equipment Catalog (Larson 1980), which is available from the Government Printing Office, Washington, D.C.

Transplants

An alternative to direct seeding is transplanting--a laborious and relatively expensive procedure for growing wildland species. Seedlings are started in the greenhouse, grown in a lathhouse or nursery, and then transplanted in the field.

Obviously, the advantage of transplanting is that the critical stages of germination and early seedling establishment are carried out in relatively controlled environments. This is especially advantageous when dealing with naturally dormant seeds that have to receive enhancement treatments before they will germinate.

Generally, there are two methods of handling plant materials for transplanting--bare root and container grown. Historically, material for transplanting has been grown in beds and then lifted as bare-root seedlings for transplanting.

Containerized Seedlings

During the 1970's, the use of containerized seedlings has increased dramatically, especially for conifer tree seedlings (Tinus et al. *1974*). Containerized systems have also been tested with hardwoods, shrubs, forbs, and grasses. The major advantages of containerized stock have been increased survival and superior initial growth rates. Also, containerized planting stock is adaptable to mechanized planting methods on flat to moderately sloping lands.

Containerized seedlings are not the same as potted seedlings. Potted seedlings are bare-root stock that are transplanted into pots filled with suitable growing media and allowed to grow for an additional year. The potted seedlings are then outplanted, with or without the container. The containerized system involves the placement of seeds directly into a container with growing media. Germination and growth occur under some form of enclosed environment regulation, usually in greenhouses. Containerized stock is usually more uniform in size because of the greater control over moisture, nutrients, and temperature in the greenhouse. After the containerized stock has reached the desirable planting size, the seedlings are hardened off for at least 2 to 3 weeks before outplanting. Depending on the type of container used, either the container with the seedling is planted or the seedling is removed from the container just prior to planting. The systems in which the seedlings is removed from the container and then planted are often referred to as plug seedlings. In either case, the root systems of the seedlings are better protected during handling and planting than they are with bare-root stock.

The potential of the containerized system of planting for western wildland plants appears to be good. Native shrub and forb seeds are usually expensive, even when they are available. Growing containerized stock makes the most efficient use of valuable seed. Containerized systems are capable of growing seedlings quickly, usually in less than 1/2 to 1/3 of the time required for stock grown in nurseries. Since greenhouse operations can be highly mechanized, the problem of locating seasonal labor is reduced.

Generally, containerized stock is recommended on adverse sites where either climate or soil are unfavorable. Containerized stock is especially promising for mine reclamation where both of the above conditions are usually present and for revegetation along highway cuts where prompt establishment of ground cover is important.

The principal disadvantage of the containerized system is that production costs are often higher than those for bare-root stock (Colby and Lewis *1973*). Containerized stock is also more expensive to transport than bare-root stock because of the additional weight of the containers and growing media. Containerized stock also requires greater care from the time it leaves the greenhouse until it is outplanted. Containerized stock must be hardened and kept moist before planting. Planting costs vary depending on the methods and the difficulty of the sites. The higher cost of containerized stock may be offset by its higher survival rates. The cost per surviving seedling should be considered rather than the cost per planted seedling.

Although the containerized system offers several advantages over conventional methods, it is doubtful that any one system for rearing the wide variety of species utilized in the revegetation of western wildlands can provide the desired survival on all sites. One of the greatest research needs at the present is to determine the proper degree of hardening before many of the shrub and forb species can be outplanted successfully.

Greenhouse and Lathhouse

Whatever method is used for propagating seedlings, the greenhouse provides a necessary environment for accelerated growth of the young plants. If the seeds are germinated in flats, the resulting seedlings must be transplanted to individual containers or more widely spaced beds to obtain optimum growth.

Except for seedlings of coniferous species, which may grow in the nursery for 2 years before transplanting to the field, most woody or perennial herbaceous species used in revegetation work are transplanted the same season they are started. This involves a sequence of germinating seeds in the fall, obtaining optimum growth in the greehouse during the winter, and hardening off in the lathhouse before transplanting in the spring. Unfortunately, for many species, this sequence is too abrupt for successful spring planting except in milder climates. In northern and mountain areas, it is usually necessary to carry the plants through the summer and following winter in the lathhouse before transplanting them to the field. This greatly increases the expense of this type of propagation.

The lathhouse, or shadehouse, provides a vital cushion between the greenhouse and field environments. To survive the shock of field conditioned, controlled watering and shade in the lathhouse hardens tender greenhouse-raised plant material.

Fertilizers

Many harsh environments, such as roadcuts, are infertile, and the addition of nitrogen (sometimes also phosphorus and/or sulfur) will aid transplant estab-

lishment, or provide additional growth, or both. Some species will benefit and some will not. Stimulation of fall growth so some species may result in winterkill. The use of fertilizer may stimulate weeds with the result that better establishment is achieved when no fertilizer is used. Fertilized plants are also more palatable and may suffer increased animal damage. Care must be taken not to fertilize with greater amounts than the young plant can utilize or to allow direct contact of the fertilizer and transplant roots.

Weed Control

Whether direct seeding or transplanting is used for establishment of plant species on wildlands, establishment will be successful only if competition from other species is reduced. Some form of mechanical or chemical weed control is usually necessary to reduce competition.

LITERATURE CITED

Brandenburg, N. R.
1968. Bibliography of harvesting and processing forage-crop seed, 1949-1964. U.S. Department of Agriculture, Agricultural Research Service, ARS 42-135, 17 p.

Chan, F. J., R. W. Harris, and A. T. Leiser.
1977. Direct seeding of woody plants in the landscape. Division of Agricultural Science, University of California, Leaflet No. 2577, 13 p.

Colby, M. K., and G. D. Lewis.
1973. Economics of containerized conifer seedlings. U.S. Department of Agriculture, Forest service, Fort Collins, Colo. 7 p.

Copeland, L. O.
1976. Principles of seed science and technology. Burgess Publishing Co., Minneapolis, Minn. 368 p.

Emery, D.
1964. Seed propagation of native California plants. Santa Barbara Botanical Garden Leaflet 1(10):81-96.

Grabe, D. F., editor.
1970. Tetrazolium testing handbook. Contribution No. 29 to the Handbook on seed testing. Association of Official Seed Analysts, 62 p.

Harmond, J. E., N. R. Brandenburg, and L. M. Klein.
1968. Mechanical seed cleaning and handling. U.S. Department of Agriculture, Agriculture Handbook No. 354, 56 p.

________ and L. M. Klein.
1964. A versatile plot thresher. U.S. Department of Agriculture, Agricultural Research Service Note ARS 42-4-1, 7 p.

________ J. E. Smith, Jr., and J. K. Park.
1961. Harvesting the seeds of grasses and legumes. P. 181-188. *In* Seeds, the Yearbook of Agriculture, U.S. Department of Agriculture, Washington, D.C.

Harrington, J. F.
1973. Problems of seed storage. *In* W. Heydecker, editor, Seed ecology, Pennsylvania State University Press, University Park, Pa., and London. 578 p.

Hartman, J. T., and D. E. Kester.
1968. Sexual propagation. P. 53-188. *In* Plant propagation--principles and practice. Prentice Hall, Englewood Cliffs, N. J.

Hary, E. M., J. W. Collier, and M. J. Norris.
1969. A simple harvester for perennial grass seeds. Agronomy Notes (July-August) 24-27. Agronomy and Range Science, University of California, Davis.

Heydecker, W., editor.
1973. Seed ecology. Pennsylvania State University Press, University Park, Pa., and London. 578 p.

Hopkins, A. D.
1918. Periodical events and natural law as guides to agricultural research and practice. U.S. Monthly Weather Review Supplement 9: 5-42.

Larson, J. E.
1980. Revegetation equipment catalog. U.S. Department of Agriculture, Forest Service, Missoula, Mont. 197 p.

McKenzie, D. W.
1977. Survey of high-production grass seed collectors. Project Record. U.S. Department of Agriculture, Forest Service, Equipment Development Center, San Dimas, Calif., 13 p.

Maguire, J. D., and A. Overland.
1959. Laboratory germination of seeds of weedy and native plants. Washington Agricultural Experiment Station Circular No. 349, 15 p.

Mirov, N. T., and C. J. Kraebel.
1939. Collecting and handling seeds of wild plants. U.S. Department of Agriculture, Civilian Conservation Corps, Forestry Publication No. 5, 42 p.

Mitrakos, K., and W. Shropshire, Jr., editor.
1971. Phytochrome. Academic Press, London and New York. 631 p.

Nord, E. C.
1963. Bitterbrush seed harvesting: When, where, and how. Journal of Range Management 16:258-261.

Peterson, B. O.
1957. Bitterbrush (*Purshia tridentata*) seed dormancy broken with thiourea. Journal of Range Management 10:41-42.

Plummer, A. P., D. E. Christensen, and S. B. Monsen.
1968. Restoring big-game in Utah. Utah Division of Fish and Game Publication No. 68-3, 183 p.

Schneegas, E. R., and J. Graham.
1967. Bitterbrush seed collecting by machine or by hand. Journal of Range Management 20:99-102.

Schopmeyer, C. S., editor.
1974. Seeds of woody plants in the United States. U.S. Department of Agriculture, Agriculture Handbook No. 450, 878 p.

Spencer, J. S., Rashelof, V. M., and Young, J. A.
1979. Safety modification for operations and transportation of the rangeland drill. Journal of Range Management 32:406-407.

Storey, C. L., R. D. Speirs, and L. S. Henderson.
1979. Insect control in farm-stored grain. U.S. Department of Agriculture Farmers' Bulletin No. 2269, 18 p.

Tinus, R. W., W. I. Stein, and W. E. Balmer, editors.
1974. Proceedings of the North American containerized forest tree seedlings symposium, Denver, Colo., Aug. 26-29, 1974. Great Plains Agricultural Council, Publication No. 68, Government Printing Office, Washington, D.C. 458 p.

U.S. Department of Agriculture.
1948. Woody plant seed manual. Miscellaneous Publication No. 654, 416 p.

____
1979. Stored-grain insects. U.S. Department of Agriculture, Agriculture Handbook No. 500, 54 p.

GLOSSARY

Achene.--A small, dry, hard, indehiscent, one-seed fruit.

Afterripening.--The collective changes that occur in a dormant seed that makes it capable of germination. Usually denotes physiological change.

Air-screen cleaner.--The basic piece of equipment for cleaning seed, utilizing airflow and perforated screens. Also called a fanning mill.

Anthesis.--Strictly, the time of expansion of the flower, but also the period during which the flower is open and functional.

AOSA.--Association of Official Seed Analysts.

Aril.--A portion of the placenta adhering about the hilum of a seed.

Aspirator.--An airblast seed separator.

Awn.--A terminal, slender bristle on an organ, such as a grass caryopsis.

Beard.--Strong, stiff hair. Often used for awn.

Berry.--A simple, fleshy or pulpy and, usually, many-seeded fruit.

Bract.--A reduced leaf subtending a flower, usually associated with an inflorescence.

Callus.--A hard or thickened layer at the base of certain grass florets.

Calyx.--The external, usually green, whorl of a flower, contrasted with the inner showy corolla.

Capsule.--A dry, dehiscent fruit composed of more than one carpel.

Caryopsis.--The grain or fruit of grasses.

Chaff.--The seed covering and other debris separated from the seed during threshing.

Corolla.--The inner perianth of a flower, composed of colored petals.

Corymb.--An indeterminant inflorescence in which the lower pedicels arising from the peduncle are successively longer than the upper ones, giving a rounded or flat-topped appearance.

Cotyledon.--Seed leaf of the embryo.

Culm.--The type of hollow or pithy, slender stem found in grasses and sedges.

Cyme.--A type of inflorescence in which the main axis ends in a flower.

Dehiscence.--The splitting open at maturity of pods of capsules along definite lines or sutures.

Dormancy.--A physical or physiological condition of a viable seed that prevents germination even in the presence of otherwise favorable germination conditions.

Embryo.--The beginning of a plant or apparent plantlet in a seed.

Endocarp.--Inner layer of the fruit wall or pericarp.

Endosperm.--The tissue of seeds that develop from sexual fusion of the polar nuclei of the ovule and the second male sperm cell.

Far-red light.--The radiant energy in the long wavelength range of the visible spectrum between 700 and 760 nanometers.

Florets.--The individual flowers of the sunflower and grass families.

Fruit.--A mature ovary and any associated parts.

Gibberellic acids.--A group of growth-promoting substances first discovered in the Gibberella spp. They regulate growth responses and appear to be a universal component of seeds.

Glumes.--The pair of bracts that occurs at the base of a grass spikelet.

Hard seed.--A seed that is dormant because of its seedcoat and is impervious to either water or oxygen.

Hilum.--The scar remaining on the seed at the place of its detachment from the seedstalk.

Imbibition.--The initial step in seed germination involving the uptake of moisture by absorption of seed tissue from the germination media.

Indehiscent.--Pods or capsules that do not split open at maturity along definite lines or sutures.

Indeterminate flower.--A flower that terminates in a bud, which continues to be meristematic throughout the growing season, resulting in flowers of different maturity within the same inflorescence.

Inflorescence.--The flowering structure of a plant, for example, the umbel, spike, or panicle.

ISTA.--International Seed Testing Association.

Lemma.--One of two bracts of the grass floret.

Meristematic.--A formative plant tissue made up of cells capable of dividing indefinitely and giving rise to new cells.

Noxious weed.--A weed species that is defined by law as being a threat to agriculture, to living beings, or to the general public.

Palea.--One of the thin bracts of grass floret enclosing the caryopsis and located on the side opposite the embryo.

Pappus.--The modified calyx-limb in Compositae, consisting of a crown of bristles or scales on the summit of the achene.

Pedicel.--The stalk of a single flower cluster or of a spikelet in grasses.

Peduncle. -The general term for the stalk of a flower or a cluster of flowers.

Pericarp.--The ripened walls of the ovary, referring to a fruit.

Phenology.--The study of growth stages of plants.

Raceme.--A simple, elongated inflorescence with each flower of nearly equal length stalks.

Rachis.--The central stem or axis of a spike, raceme, or compound leaf.

Scalp screen.--A separation screen on which waste material stays on top and seed to be saved drops through.

Scarification.--The process of mechanically or chemically abrading a seedcoat to make it more permeable to water.

Second-year twig.--Twig produced during previous growing season in contrast to current annual growth, which is produced in the same season as flowering occurs.

Seedcoat.--The protective covering of a seed.

Sepal.--A leaf or segment of the calyx.

Sessile.--Attached directly by the base, not stalked.

Spike.--A basic type of inflorescence in which the flowers arise along the rachis and are essentially sessile.

Spikelet.--The unit of the grass flower that includes the two basal glumes and one or more florets.

Stratification.--The practice of exposing imbibed seeds to cool (5° to 10°C) (sometimes warm) temperatures prior to germination to break dormancy.

Tetrazolium.--A class of chemicals that have the ability to accept hydrogen atoms from dehydrogenase enzymes during the respiration process in viable seeds.

Urticle.--A small, thin-walled, one-seeded fruit in which the seed is only loosely attached to the pericarp.

Viable.--Alive. In seeds, viable indicates that a seed contains structures and substances, including enzyme systems, that give it the capacity to germinate under favorable conditions in the absence of dormancy.

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